NATIONAL OPEN UNIVERSITY OF NIGERIA

SCHOOL OF SCIENCE AND TECHNOLOGY

COURSE CODE: BIO 214

COURSE TITLE: STRUCTURE & FUNCTION OF MAJOR CELL COMPONENTS

BIO 214 Structure & Function of Major Cell Components (2 Units)

UNIT 1 CELL, THE STRUCTURAL ASPECT OF LIFE

CONTENTS

1.0 INTRODUCTION:

Part of our definition/description of what it means to be a living thing on Earth includes the assertion that living things are made of cells and cell products. In other words, we consider the cell to be a pretty fundamental structural aspect of life.

***Cell** is the basic unit of living thing. It simply put, the smallest independently functioning unit in the structure of an organism, usually consisting of one or more nuclei surrounded by cytoplasm and enclosed by a membrane. Cells are highly organized to form a simple or complex organism. In order words the nature and form of the organisms is structurally and chemically determined by cells. The two types of cells that form living things are the prokaryotic and Eukaryotic cells.*

2.0 AIMS AND OBJECTIVE:

- The student is expected to;
- Ascertain that living things are made up cells
- Show that the cell is the basic/functional unit of living things
- Identify and characterize living things based on their cellular arrangement and cell types
- To know the constituent elements of the cell and the subcellular components
- To know the origin of living organisms

3.0 MAIN TEXT

3.1 Levels of cell Organization in Living Things:

Cell organization: **Physiology** - science that describes how organisms FUNCTION and survive in continually changing environments

3.1.1 Chemical Level

Includes all chemical substances necessary for life (see, for example, a small portion - a heme group - of a hemoglobin molecule, or amino acid); together form the next higher level

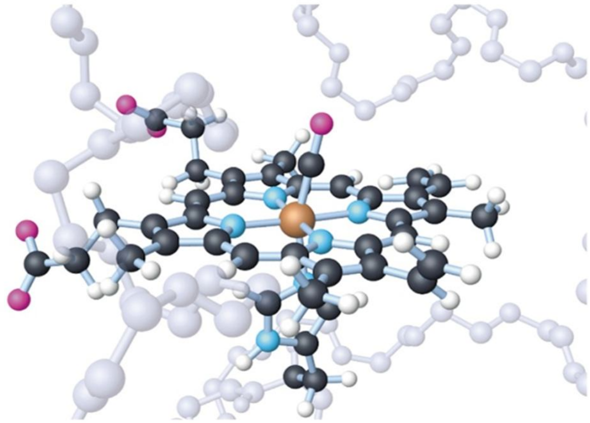


Fig: 1 cell structural arrangement base on chemical level due to bond formation

Source:http://cwx.prenhall.com/bookbind/pubbooks/hillchem3/medialib/media_portfolio/text_images/CH25/FG25_07.JPG

3.1.2 Cellular Level

Cells are the basic structural and functional units of the organisms body. Cellular arrangement is of two types; the Prokaryotic cells and Eukaryotic cells, & there are many different types of cells (e.g., muscle, nerve, blood, and so on) found in the body of living organisms.

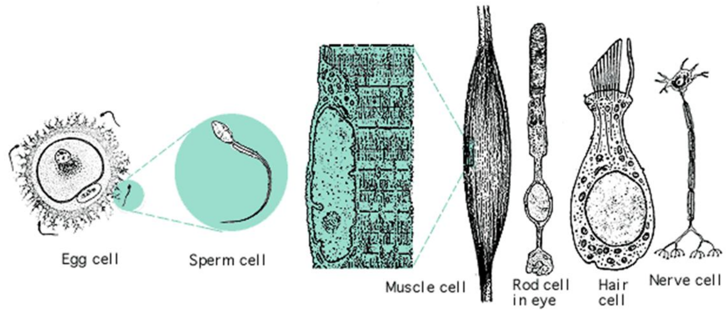


Fig 2: Cellular arrangement of cells

Source: http://www.nigms.nih.gov/news/science_ed/whatart1.html

3.1.3 Tissue Level

A tissue is a group of cells that perform a specific function and the basic types of tissues in the human body include epithelial, muscle, nervous, and connective tissues

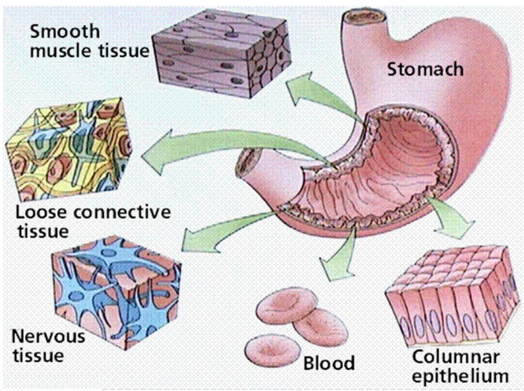


Fig 3: Arrangement of cell forming tissue, organ and system levels

3.1.4 Organ Level

An organ consists of 2 or more tissues that perform a particular function (e.g., heart, liver, stomach, and so on)

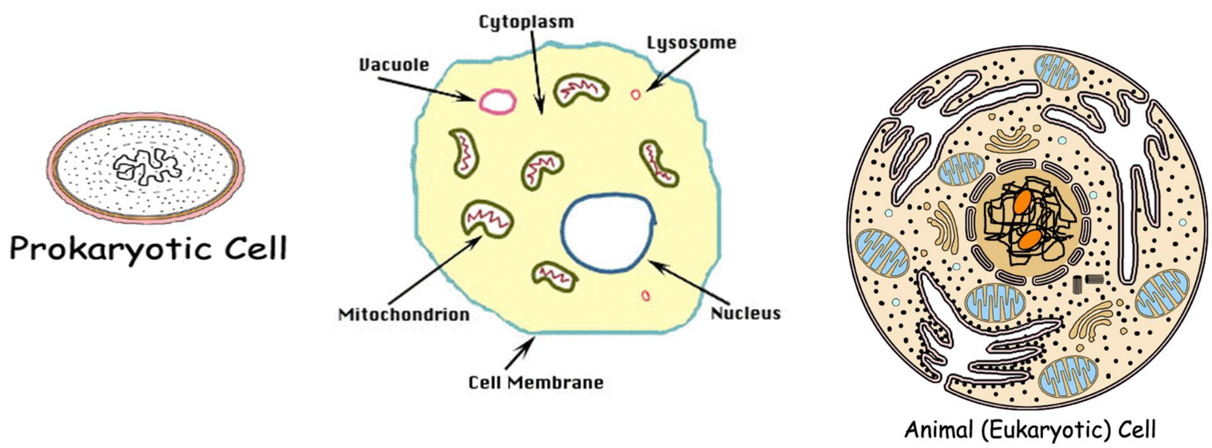
3.1.5 System Level

An association of organs that have a common function; the major systems in the human body include digestive, nervous, endocrine, circulatory, respiratory, urinary, and reproductive.

These levels of cellular organization together with the resultant tissues-organs-and-systems form the complex network of activities that take place within an organism. This net work of activities is what is referred to as the physiological processes. The physiological process of an organism could be described in two broad ways; the cellular physiology and the organ physiology. Cellular physiology explains the various activities that take place within the cell (the basic unit of life) such as cellular metabolisms and secretion, selective-permeability etc while the organ physiology explains the working principles of the various organs and the various organ systems of the organism such as respiration, excretion etc.

3.2 Types of cells

Cells in our world come in two basic types, **prokaryotic and eukaryotic**. "Karyose" comes from a Greek word which means "kernel," as in a kernel of grain. In biology, we use this word root to refer to the nucleus of a cell. "Pro" means "before," and "eu" means "true," or "good." So "Prokaryotic" means "before a nucleus (cells, like bacteria, have no 'nucleus), and "eukaryotic" means "possessing a true nucleus (like those of the human body). This is a big hint about one of the differences between these two cell types. Also it well interests you to note that Prokaryotic cells have no nuclei, while eukaryotic cells do have true nuclei. This is far from the only difference between these two cell types. However, here's a simple visual comparison between a prokaryotic cell and a eukaryotic cell as you are about to learn.



Eukaryotic cell

Figure 4: Diagrams of prokaryotic and eukaryotic cells

The particular eukaryotic cell presented in figure 1 happens to be an animal cell. It is important to also note that the cells of plants, fungi and protists are also eukaryotic.

3.3 Evolution of cells

The origin of cells has to do with the origin of life, which began with the history of life on Earth. There are several theories about the origin of small molecules that could lead to life in an early Earth. One is that they came from meteorites (*see Murchison meteorite*). Another is that they were created at deep-sea vents. A third is that they were synthesized by lightning in a reducing atmosphere (*see Miller–Urey experiment*); although it is not clear if Earth had such an atmosphere. There are essentially no experimental data defining what the first self-replicating forms were. RNA is generally assumed to be the earliest self-replicating molecule, as it is capable of both storing genetic information and catalyzing chemical reactions (*see RNA world hypothesis*). But some other entity with the potential to self-replicate could have preceded RNA, like clay or peptide nucleic acid.

Cells emerged at least 4.0–4.3 billion years ago. The current belief is that these cells were heterotrophs. An important characteristic of cells is the cell membrane, composed of a bilayer of lipids. The early cell membranes were probably more simple and permeable than modern ones, with only a single fatty acid chain per lipid. Lipids are known to spontaneously form bilayered vesicles in water, and could have preceded RNA. But the first cell membranes could also have been produced by catalytic RNA, or even have required structural proteins before they could form.

3.3.1 Evolutionary relationship of eukaryotic and prokaryotic cells

Examination of prokaryotic and eukaryotic cell differences is interesting. As mentioned above, they are all associated with larger size and greater complexity. This leads to an important observation. Yes, these cells are different from each other. However, they are clearly more alike than different, and they are clearly evolutionarily related to each other. Biologists have no significant doubts about the connection between them. The eukaryotic cell is clearly developed from the prokaryotic cell.

One aspect of that evolutionary connection is particularly interesting. Within eukaryotic cells you find a really fascinating organelle called a **mitochondrion**. And in plant cells, you'd find an additional family of organelles called **plastids**, the most famous of which is the renowned **chloroplast**. Mitochondria (the plural of mitochondrion) and chloroplasts almost certainly have a similar evolutionary origin. Both are pretty clearly the descendants of independent prokaryotic cells, which have taken up permanent residence within other cells through a well-known and very common phenomenon called **endosymbiosis**.

One structure not shown in our prokaryotic cell is called a **mesosome**. Not all prokaryotic cells have these. The mesosome is an elaboration of the plasma membrane; a sort of rosette of ruffled membrane intruding into the cell.

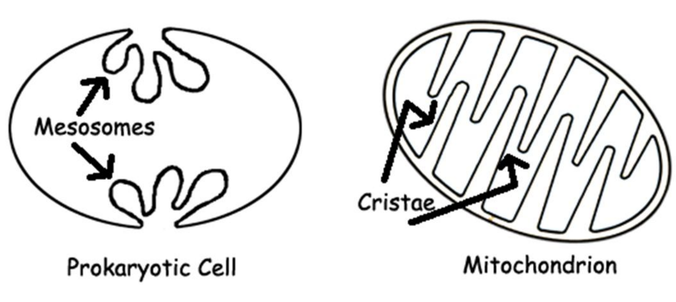


Figure 5: This diagram shows a trimmed down prokaryotic cell, including only the plasma membrane and a couple of mesosomes. A mitochondrion is included for comparison.

The similarities in appearance between these structures are pretty clear. The mitochondrion is a double-membrane organelle, with a smooth outer membrane and an inner membrane which protrudes into the interior of the mitochondrion in folds called **cristae**. This membrane is very similar in appearance to the prokaryotic plasma membrane with its mesosomes.

But the similarities are a lot more significant than appearance. Both the mesosomes and the cristae are used for the same function: they play important role in aerobic cellular respiration (Cellular respiration is the process by which a cell converts the raw, potential energy of food into biologically useful energy, and there are two general types, anaerobic i.e not using oxygen and aerobic i. e requiring oxygen) where much higher energy yield is produced than anaerobic respiration. Aerobic respiration is clearly the evolutionary offspring of anaerobic respiration. In fact, aerobic respiration really is anaerobic respiration with additional chemical sequences added on to the end of the process to allow utilization of oxygen (a very common evolutionary pattern adding new parts to old systems). So it's pretty reasonable of biologists to think that a mitochondrion evolved from a once-independent aerobic prokaryotic cell which entered into an endosymbiotic relationship with a larger, anaerobic cell.

So is there any real evidence that the distant ancestors of mitochondria were independent cells? Quite a lot, actually, and of a very convincing type, Mitochondria (and chloroplasts, for that matter) have their own genetic systems. They have their own DNA, which is not duplicated in the nucleus. That DNA contains a number of the genes which are necessary to make the materials needed for aerobic cellular respiration (or photosynthesis, in the case of the chloroplast). Mitochondrial and chloroplast DNA molecules are naked and circular, like prokaryotic DNA. These organelles also have their own population of ribosomes, which are smaller and simpler than the ribosomes out in the general cytoplasm. Mitochondria and chloroplasts also divide on their own, in a manner similar to the binary fission of prokaryotic cells.

Then there's that interesting outer membrane, another feature chloroplasts share with mitochondria. The manners by which large objects enter cells automatically create an outer membrane (actually a part of the big cell's plasma membrane) around the incoming object.

This discussion suggests a very interesting question. Endosymbiosis is a very widespread phenomenon. The more we look, the more examples we find throughout the kingdoms of life. So, if a mitochondrion is the distant descendent of an independent prokaryotic cell, is it then an organism living inside a larger cell? Or is it just a part of that larger cell? Is it an independent organism or not?

Before you leap to a conclusion, think a bit. Certainly, mitochondria are absolutely dependent upon the cells in which they reside. Like any long-time endosymbiont, they long ago gave up many of the basic life processes needed for independent life. And the cells in which they reside are completely dependent upon their mitochondria, because the anaerobic respiration they could do without the mitochondria wouldn't provide nearly enough energy for the cell's needs. In fact, it's very probable that the evolution of big, complex eukaryotic cells wasn't possible until the "invention" of aerobic respiration.

But there are many endosymbiotic relationships in nature which are just as interdependent. For example, no termite could survive without the population of endosymbionts that lives inside its guts, digesting its woody diet for it. And the protists and bacteria that make up that population can't survive outside the termite. Complete interdependency.

Now, the termite and its passengers look a lot more like independent creatures to us than a cell and its mitochondria. But they are actually no more independent of each other. So if we decide that the mitochondrion is just a part of the cell, then don't we have to also decide that the endosymbionts inside the termite's guts are just parts of the termite? If not, how do we justify insisting that there's a difference?

Before you get too frustrated trying to sort this out, allow me to relieve your mind. There is, in fact, no answer to this question, just the reinforcement of a very important lesson. Despite our human need to sort our world into neat, clean categories, the real universe often doesn't cooperate, and this is just such a case. We want to be able to decide "two separate organisms" or "parts of the same organism" in cases like this, but reality shows us that there are many situations which fall somewhere between these two categories. This is a lesson we learned when we examined the "alive" vs "not alive" issue, and again when we tried to decide how to functionally describe species. We want neat categories; nature doesn't cooperate.

3.3.2 Eukaryotic cells

The eukaryotic cell seems to have evolved from a symbiotic community of prokaryotic cells. DNA-bearing organelles like the mitochondria and the chloroplasts are almost certainly what remain of ancient symbiotic oxygen-breathing proteobacteria and cyanobacteria, respectively, where the rest of the cell seems to be derived from an ancestral Archaean prokaryote cell – a theory termed the endosymbiotic theory.

There is still considerable debate about whether organelles like the hydrogenosome predated the origin of mitochondria, or vice-versa: see the hydrogen hypothesis for the origin of eukaryotic cells.

Sex, as the stereotyped choreography of meiosis and syngamy that persists in nearly all extant eukaryotes, may have played a role in the transition from prokaryotes to eukaryotes. An 'origin of sex as vaccination' theory suggests that the eukaryote genome accreted from prokaryan parasite genomes in numerous rounds of lateral gene transfer. Sex-as-syngamy (fusion sex) arose when infected hosts began swapping nuclearized genomes containing co-evolved, vertically transmitted symbionts that conveyed protection against horizontal infection by more virulent symbionts

Eukaryotic cells are about 15 times wider than a typical prokaryote and can be as much as 1000 times greater in volume. The major difference between prokaryotes and eukaryotes is that eukaryotic cells contain membrane-bound compartments in which specific metabolic activities take place. Most important among these is a cell nucleus, a membrane-delineated compartment that houses the eukaryotic cell's DNA. This nucleus gives the eukaryote its name, which means "true nucleus." Other differences include:

- The plasma membrane resembles that of prokaryotes in function, with minor differences in the setup. Cell walls may or may not be present.
- The eukaryotic DNA is organized in one or more linear molecules, called chromosomes, which are associated with histone proteins. All chromosomal DNA is stored in the *cell nucleus*, separated from the cytoplasm by a membrane. Some eukaryotic organelles such as mitochondria also contain some DNA.
- Many eukaryotic cells are ciliated with *primary cilia*. Primary cilia play important roles in chemosensation, mechanosensation, and thermosensation. Cilia may thus be "viewed as sensory cellular antennae that coordinate a large number of cellular signaling pathways, sometimes coupling the signaling to ciliary motility or alternatively to cell division and differentiation.
- Eukaryotes can move using *motile cilia* or *flagella*. The flagella are more complex than those of prokaryotes.

3.3.3 Features of Prokaryotic Cells

- Prokaryotes, which include all bacteria and archaea (archaebacteria), are the simplest cellular organisms.
- Prokaryotic cells are fundamentally different in their internal organization from eukaryotic cells. Notably, prokaryotic cells lack a nucleus and membranous organelles.

3.3.4 Features of Eukaryotic Cells

- Eukaryotic cells contain a membrane-bound nucleus and numerous membrane-enclosed organelles (e.g., mitochondria, lysosomes, Golgi apparatus) not found in prokaryotes.
- Prokaryotic cells are fundamentally different in their internal organization from eukaryotic cells. Notably, prokaryotic cells lack a nucleus and membranous organelles.
- The nucleus is bounded by the nuclear envelope, a double membrane with many nuclear pores through which material enters and leaves. Animals, plants, fungi, and protists are all eukaryotes. Eukaryotic cells are more complex than prokaryotic cells and are found in a great many different forms.

3.3.5 Differences and similarities of prokaryotic and Eukaryotic cells

Similarities

Despite their apparent differences, these two cell types (prokaryotic and eukaryotic) have a lot in common:

i. They perform most of the same kinds of functions, and in the same ways.
ii. Both are enclosed by plasma membranes, filled with cytoplasm, and
iii. They cytoplasm of both cells types are loaded with small structures called ribosomes.
iv. Both have DNA which carries the archived instructions for operating the cell.

v. The similarities go far beyond the visible--physiologically they are very similar in many ways. For example, the DNA in the two cell types is precisely the same kind of DNA, and the genetic code for a prokaryotic cell is exactly the same genetic code used in eukaryotic cells.
vi. Some things which seem to be different aren't. For example, the prokaryotic cell has a cell wall, while some animal cells do not. However, many kinds of eukaryotic cells do have cell walls.

Differences

Despite all of these similarities mentioned above, the differences are also clear. It's pretty obvious from these two little pictures (figure 1) that there are two general categories of difference between these two cell types: **size** and **complexity**. If we take a closer look at the comparison of these cells, we see the following differences:

i. Eukaryotic cells are much larger and much more complex than prokaryotic cells. These two observations are not unrelated to each other.
ii. Eukaryotic cells have a true nucleus, bound by a double membrane. Prokaryotic cells have no nucleus. The purpose of the nucleus is to sequester the DNA-related functions of the big eukaryotic cell into a smaller chamber, for the purpose of increased efficiency. This function is unnecessary for the prokaryotic cell, because it’s much smaller size means that all materials within the cell are relatively close together. Of course, prokaryotic cells do have DNA and DNA functions. Biologists describe the central region of the cell as its "nucleoid" (-oid=similar or imitating), because it's pretty much where the DNA is located. But note that the nucleoid is essentially an imaginary "structure." There is no physical boundary enclosing the nucleoid.
iii. Eukaryotic DNA is linear; prokaryotic DNA is circular (it has no ends).
iv. Eukaryotic DNA is complexed with proteins called "histones," and is organized into chromosomes; prokaryotic DNA is "naked," meaning that it has no histones associated with it, and it is not formed into chromosomes. Though many are sloppy about it, the term "chromosome" does not technically apply to anything in a prokaryotic cell.
v. A eukaryotic cell contains a number of chromosomes; a prokaryotic cell contains only one circular DNA molecule and a varied assortment of much smaller circlets of DNA called "plasmids."
vi. The smaller, simpler prokaryotic cell requires far fewer genes to operate than the eukaryotic cell.
vii. Both cell types have many, many ribosomes, but the ribosomes of the eukaryotic cells are larger and more complex than those of the prokaryotic cell. Ribosomes are made out of special class of RNA molecules (ribosomal RNA, or rRNA) and a specific collection of different proteins. A eukaryotic ribosome is composed of five kinds of rRNA and about eighty kinds of proteins. Prokaryotic ribosomes are composed of only three kinds of rRNA and about fifty kinds of protein.

The cytoplasm of eukaryotic cells is filled with a large, complex collection of organelles, many of them enclosed in their own membranes; the prokaryotic cell contains no membrane-bound organelles which are independent of the plasma membrane. This is a very significant difference, and the source of the vast majority of the greater complexity of the eukaryotic cell. There is much more space within a eukaryotic cell than within a prokaryotic cell, and many of these structures, like the nucleus, increase the efficiency of functions by confining them within smaller spaces within the huge cell, or with communication and movement within the cell.

Table 1: Comparison of features of prokaryotic and eukaryotic cells

	Prokaryotes	Eukaryotes
Typical organisms	bacteria, archaea	protists, fungi, plants, animals
Typical size	~ 1–10 µm	~ 10–100 µm (sperm cells, apart from the tail, are smaller)
Type of nucleus	nucleoid region; no real nucleus	real nucleus with double membrane
DNA	circular (usually)	linear molecules (chromosomes) with histone proteins
RNA-/protein-synthesis	coupled in cytoplasm	RNA-synthesis inside the nucleus protein synthesis in cytoplasm
Ribosomes	50S+30S	60S+40S
Cytoplasmatic structure	very few structures	highly structured by endomembranes and a cytoskeleton
Cell movement	flagella made of flagellin	flagella and cilia containing microtubules; lamellipodia and filopodia containing actin
Mitochondria	None	one to several thousand (though some lack mitochondria)
Chloroplasts	None	in algae and plants
Organization	usually single cells	single cells, colonies, higher multicellular organisms with specialized cells
Cell division	Binary fission (simple division)	Mitosis (fission or budding) Meiosis

Table 2: Comparison of structures between animal and plant cells

	Typical animal cell	Typical plant cell
Organelles	• Nucleus o Nucleolus (within nucleus) • Rough endoplasmic reticulum (ER) • Smooth ER • Ribosomes • Cytoskeleton • Golgi apparatus • Cytoplasm • Mitochondria • Vesicles • Lysosomes • Centrosome o Centrioles	• Nucleus o Nucleolus (within nucleus) • Rough ER • Smooth ER • Ribosomes • Cytoskeleton • Golgi apparatus (dictiosomes) • Cytoplasm • Mitochondria • Plastids and its derivatives • Vacuole(s) • Cell wall

3.3.6 Common Features of All Cells

All cells, whether they are prokaryotic or eukaryotic, have some common features.

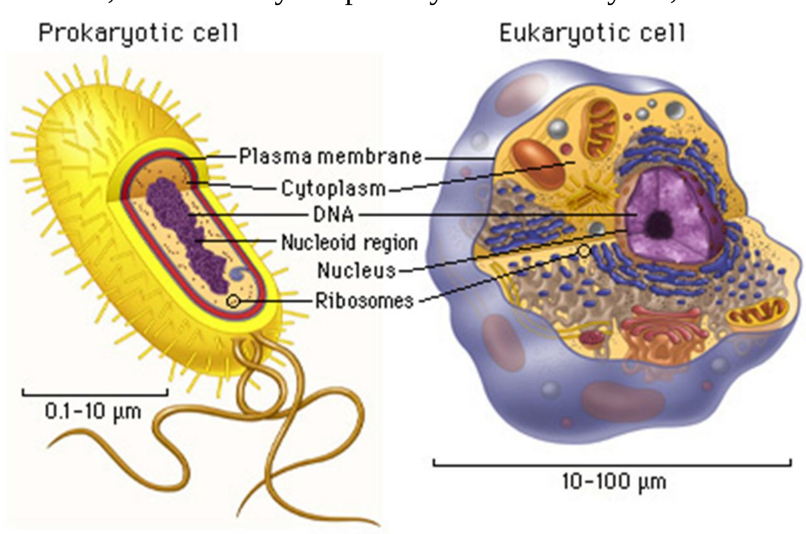


Fig 6: A Prokaryotic and Eukaryotic cell

The common features of prokaryotic and eukaryotic cells are:

1. **DNA**, the genetic material contained in one or more chromosomes and located in a nonmembrane bound nucleoid region in prokaryotes and a membrane-bound nucleus in eukaryotes

2. **Plasma membrane**: This is a phospholipid bilayer with proteins that separates the cell from the surrounding environment and functions as a selective barrier for the import and export of

materials.

3. **Cytoplasm**, the rest of the material of the cell within the plasma membrane, excluding the nucleoid region or nucleus, that consists of a fluid portion called the cytosol and the organelles and other particulates suspended in it.

4. **Ribosomes**, the organelles on which protein synthesis takes place

UNIT 2: ELEMENTARY TREATMENT OF MEMBRANE STRUCTURE AND FUNCTIONS IN EUKARYOTIC CELLS

CONTENT

1.0 Introduction

All eukaryotic cells have within them a functionally interrelated membrane system, the endomembrane system consisting of the nuclear envelope, ER and Golgi apparatus, vesicles and other organelles derived from them, and the plasma membrane. the section also highlights on many types of materials that moved around the cell by the endomembrane system, including some proteins. The role and functions of the endomembrane system of the cell are also pinpointed.

2.0 Aims and Objectives

- To determine the basic functional unit that makes up all forms of living things
- To ascertain the nature and function of the membrane and the endomembrane system in living things
- To also find out the constituent composition of the cell (i.e. the various organelles that make up the cell)
- To study the various types of materials that move in and around the cell

3.0 Main Text

3.1 Cell membrane

The cell membrane is a biological membrane that separates the interior of all cells from the outside environment. The cell membrane is selectively-permeable to ions and organic molecules and controls the movement of substances in and out of cells. It consists of the phospholipid bilayer with embedded proteins. Cell membranes are involved in a variety of cellular processes such as cell adhesion, ion conductivity and cell signaling and serve as the attachment surface for the extracellular glycocalyx and cell wall and intracellular cytoskeleton.

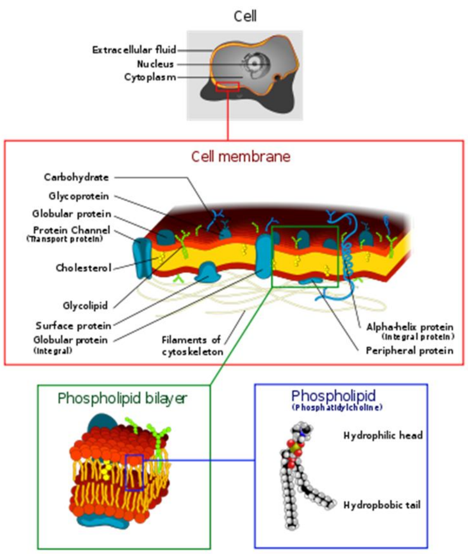
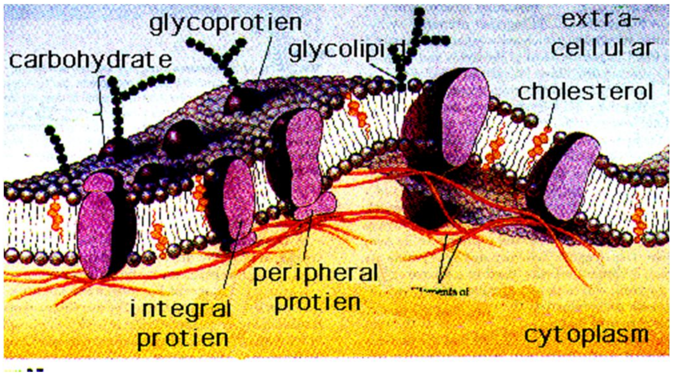


Figure 7: Illustration of a Eukaryotic cell membrane

A) inside of the cell membrane



B) Outside of the cell

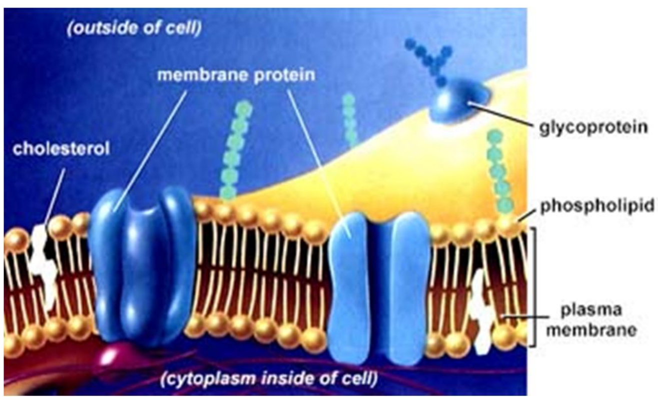


Figure 8: Treatment of membrane structure or the mosaic properties of cell membranes

3.2 Structure of the cell membrane

The cell membrane is typical of the mosaic structure with different kinds of macromolecules. The cell membrane has 2 primary building blocks:

i. Include protein (integral proteins, peripheral proteins, glycoproteins). This protein molecules form about 60% of the membrane and lipid, or fat (about 40% of the membrane).
ii. ii. The primary lipid is called phospholipid (phospholipids, glycolipids, and in some cases cholesterol, lipoproteins.), and molecules of phospholipid form a 'phospholipid bilayer' (two layers of phospholipid molecules). This bilayer forms because the two 'ends' of phospholipid molecules have very different characteristics: one end is polar (or hydrophilic) and one (the hydrocarbon tails below) is non-polar (or hydrophobic):

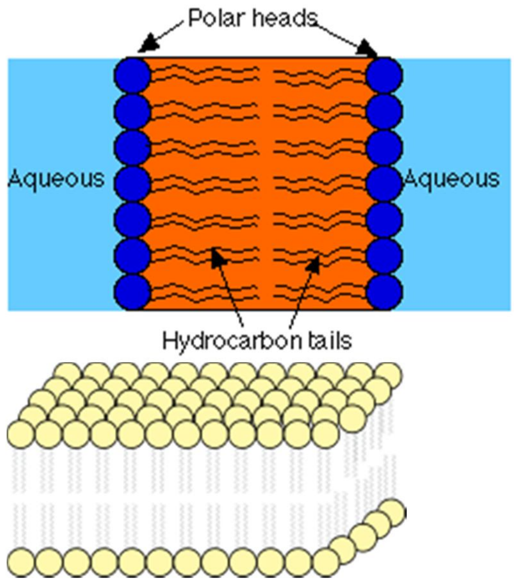


Fig 9: Shows the diagram of the arrangement of amphipathic lipid molecules to form a lipid bilayer. The yellow polar head groups separate the grey hydrophobic tails from the aqueous cytosolic and extracellular environments.

In addition to being composed of different components, the relative amounts of these components can vary from membrane to membrane. The table below shows some of the variation in protein, lipid and carbohydrate content of some membranes.

Lipid bilayers go through a self assembly process in the formation of membranes. The cell membrane consists primarily of a thin layer of amphipathic phospholipids which spontaneously arrange so that the hydrophobic "tail" regions are shielded from the surrounding polar fluid, causing the more hydrophilic "head" regions to associate with the cytosolic and extracellular faces of the resulting bilayer. This forms a continuous, spherical lipid bilayer. Forces such as Van der Waal, electrostatic, hyrdogen bonds, and noncovalent interactions, are all forces that contribute to the formation of the lipid bilayer. Overall, hydrophobic interactions are the major driving force in the formation of lipid bilayers.

Lipid bilayers have very low permeability for ions and most polar molecules.The arrangement of hydrophilic heads and hydrophobic tails of the lipid bilayer prevent polar solutes (e.g. amino acids, nucleic acids, carbohydrates, proteins, and ions) from diffusing across the membrane, but generally allows for the passive diffusion of hydrophobic molecules. This affords the cell the ability to control the movement of these substances via transmembrane protein complexes such as pores and gates.

Table 1: variation in mineral composition of some membrane

Membrane	% protein	% lipid	% carbohydrate
Myelin	18	79	3
human erythrocyte plasma membrane	49	43	8
mitochondrial inner membrane	79	24	0
amoeba plasma membrane	54	42	4

Not only do membranes vary in the relative amount of lipid they contain, the kinds of lipids in membranes can also vary (Table 2).

Table 2: Proportions of various kinds of lipids in different membranes.

Membrane	Type of lipid				
	cholesterol	phosphotidyl-choline	sphingo-myelin	phosphotidyl-serine	glycolipids
rat liver plasma membrane	30	18	14	9	-
rat liver RER	6	55	3	3	-
rat liver nuclear membrane	10	55	3	3	-
rat liver myelin	22	11	6	7	12
E coli cytoplasmic membrane	0	0	-	-	-

3.3 Fluid mosaic model

According to the fluid mosaic model of S. J. Singer and Garth Nicolson 1972, the biological membranes can be considered as a two-dimensional liquid where all lipid and protein molecules diffuse more or less easily. This picture may be valid in the space scale of 10 nm. However, the plasma membranes contain different structures or domains that can be classified as: (a) protein-protein complexes; (b) lipid rafts, and (c) pickets and fences formed by the actin-based cytoskeleton.

Question: what are polar and hydrophobic molecules?

Question: How does cell membrane prevent the passage of polar solutes from diffusing across the membrane but generally allows for the passive diffusion of hydrophobic molecules?

3.4 Function of cell membrane

i. The cell membrane surrounds the protoplasm of a cell and, in animal cells, physically separates the intracellular components from the extracellular environment. Fungi, bacteria and plants also have the cell wall which provides a mechanical support for the cell and precludes passage of the larger molecules.
ii. The cell membrane also plays a role in anchoring the cytoskeleton to provide shape to the cell, and in attaching to the extracellular matrix and other cells to help group cells together to form tissues.
iii. The barrier is differentially permeable and able to regulate what enters and exits the cell, thus facilitating the transport of materials needed for survival. The movement of substances across the membrane can be either *passive*, occurring without the input of cellular energy, or active, requiring the cell to expend energy in moving it.
iv. The membrane also maintains the cell potential.

3.4.1 Transport of materials in and out of the cell

Membranes serves important role in regulating the movement of materials into and out of cells. The phospholipid bilayer structure (fluid mosaic model) with specific membrane proteins accounts for the selective permeability of the membrane and passive and active transport mechanisms. In addition, membranes in prokaryotes and in the mitochondria and chloroplasts of eukaryotes facilitate the synthesis of ATP through chemiosmosis.

3.4.2 Other functions include:

i. Supporting and retaining the cytoplasm being a selective barrier. The cell is separated from its environment and needs to get nutrients in and waste products out. Some molecules can cross the membrane without assistance, most cannot. Water, non-polar molecules and some small polar molecules can cross. Non-polar molecules penetrate by actually dissolving into the lipid bilayer. Most polar compounds such as amino acids, organic acids and inorganic salts are not allowed entry, but instead must be specifically transported across the membrane by proteins.
ii. Transport. Many of the proteins in the membrane function to help carry out selective transport. These proteins typically span the whole membrane, making contact with the outside environment and the cytoplasm. They often require the expenditure of energy to help compounds move across the membrane
iii. Communication (via receptors)

Source: http://bio.winona.msus.edu/berg/ANIMTNS/Recep.htm

3.5 Membrane polarity

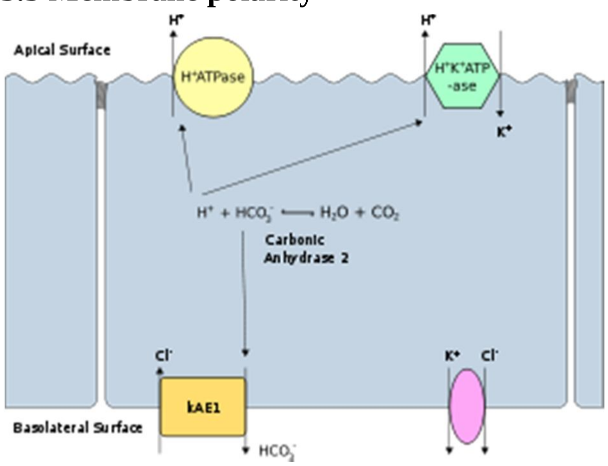


Fig 10: Alpha intercalated cell arrangement of a polarized cell membrane

The **apical membrane** of a polarized cell is the surface of the plasma membrane that faces the lumen. This is particularly evident in epithelial and endothelial cells, but also describes other polarized cells, such as neurons.

The **basolateral membrane** of a polarized cell is the surface of the plasma membrane that forms its basal and lateral surfaces. It faces towards the interstitium, and away from the lumen.

"Basolateral membrane" is a compound phrase referring to the terms *basal (base) membrane* and *lateral (side) membrane*, which, especially in epithelial cells, are identical in composition and activity. Proteins (such as ion channels and pumps) are free to move from the basal to the lateral surface of the cell or *vice versa* in accordance with the fluid mosaic model.

Tight junctions that join epithelial cells near their apical surface prevent the migration of proteins from the basolateral membrane to the apical membrane. The basal and lateral surfaces thus remain roughly equivalent to one another, yet distinct from the apical surface.

3.6 Integral membrane proteins

The cell membrane contains many integral membrane proteins, which pepper the entire surface. These structures, which can be visualized by electron microscopy or fluorescence microscopy, can be found on the inside of the membrane, the outside, or membrane spanning. These may include integrins, cadherins, desmosomes, clathrin-coated pits, caveolaes, and different structures involved in cell adhesion. Integral proteins are the most abundant type of protein to span the lipid bilayer. They interact widely with hydrocarbon chains of membrane lipids and can be released by agents that compete for the same nonpolar interactions.

3.7 Peripheral membrane proteins

Peripheral proteins are proteins that are bounded to the membrane by electrostatic interactions and hydrogen bonding with the hydrophilic phospholipid heads. Many of these proteins can be found bounded to the surfaces of integral proteins on either the cytoplasimic side of the cell or the extracellular side of the membrane. Some are anchored to the bilayer through covalent bond with a fatty acid.

3.8 Membrane skeleton

The cytoskeleton is found underlying the cell membrane in the cytoplasm and provides a scaffolding for membrane proteins to anchor to, as well as forming organelles that extend from the cell. Indeed, cytoskeletal elements interact extensively and intimately with the cell membrane. Anchoring proteins restricts them to a particular cell surface — for example, the *apical surface* of epithelial cells that line the vertebrate gut — and limits how far they may diffuse within the bilayer. The cytoskeleton is able to form appendage-like organelles, such as cilia, which are microtubule-based extensions covered by the cell membrane, and filopodia, which are actin-based extensions. These extensions are ensheathed in membrane and project from the surface of the cell in order to sense the external environment and/or make contact with the substrate or other cells. The apical surfaces of epithelial cells are dense with actin-based finger-like projections known as microvilli, which increase cell surface area and thereby increase the absorption rate of nutrients. Localized decoupling of the cytoskeleton and cell membrane results in formation of a bleb.

3.9 Lipids

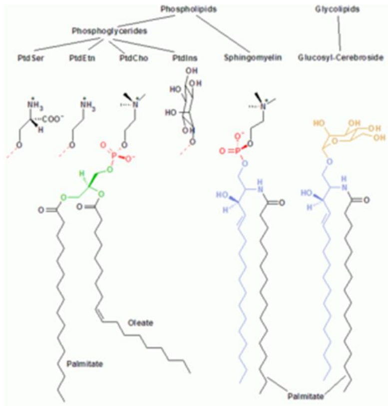


Figure 11: Examples of the major membrane phospholipids and glycolipids: phosphatidylcholine (PtdCho), phosphatidylethanolamine (PtdEtn), phosphatidylinositol (PtdIns), phosphatidylserine (PtdSer).

The cell membrane consists of three classes of amphipathic lipids: phospholipids, glycolipids, and cholesterols. The amount of each depends upon the type of cell, but in the majority of cases phospholipids are the most abundant. In RBC studies, 30% of the plasma membrane is lipid.

The fatty chains in phospholipids and glycolipids usually contain an even number of carbon atoms, typically between 16 and 20. The 16- and 18-carbon fatty acids are the most common. Fatty acids may be saturated or unsaturated, with the configuration of the double bonds nearly always *cis*. The length and the degree of unsaturation of fatty acid chains have a profound effect on membrane fluidity as unsaturated lipids create a kink, preventing the fatty acids from packing together as tightly, thus decreasing the melting temperature (increasing the fluidity) of the membrane. The ability of some organisms to regulate the fluidity of their cell membranes by altering lipid composition is called homeoviscous adaptation.

The entire membrane is held together via non-covalent interaction of hydrophobic tails, however the structure is quite fluid and not fixed rigidly in place. Under physiological conditions phospholipid molecules in the cell membrane are in the liquid crystalline state. It means the lipid molecules are free to diffuse and exhibit rapid lateral diffusion along the layer in which they are present. However, the exchange of phospholipid molecules between intracellular and extracellular leaflets of the bilayer is a very slow process. Lipid rafts and caveolae are examples of cholesterol-enriched microdomains in the cell membrane.

In animal cells cholesterol is normally found dispersed in varying degrees throughout cell membranes, in the irregular spaces between the hydrophobic tails of the membrane lipids, where it confers stiffening and strengthening effect on the membrane.

3.9.1 Phospholipids forming lipid vesicles

Lipid vesicles or liposomes are circular pockets that are enclosed by a lipid bilayer. These structures are used in laboratories to study the effects of chemicals in cells by delivering these chemicals directly to the cell, as well as getting more insight into cell membrane permeability. Lipid vesicles and liposomes are formed by first suspending a lipid in an aqueous solution then agitating the mixture through sonication, resulting in a uniformly circular vesicle. By measuring the rate of efflux from that of the insideof the vesicle to the ambient solution, allows researcher to better understand membrane permeability. Vesicles can be formed with molecules and ions inside the vesicle by forming the vesicle with the desired molecule or ion present in the solution. Proteins can also be embedded into the membrane through solubilizing the desired proteins in the presence of detergents and attaching them to the phospholipids in which the liposome is formed. These provide researchers with a tool to examine various membrane protein functions.

3.9.2 Carbohydrates

Plasma membranes also contain carbohydrates, predominantly glycoproteins, but with some glycolipids (cerebrosides and gangliosides). For the most part, no glycosylation occurs on membranes within the cell; rather generally glycosylation occurs on the extracellular surface of the plasma membrane.

The glycocalyx is an important feature in all cells, especially epithelia with microvilli. Recent data suggest the glycocalyx participates in cell adhesion, lymphocyte homing, and many others.

The penultimate sugar is galactose and the terminal sugar is sialic acid, as the sugar backbone is modified in the golgi apparatus. Sialic acid carries a negative charge, providing an external barrier to charged particles.

3.9.3 Proteins

Proteins within the membrane are key to the functioning of the overall membrane. These proteins mainly transport chemicals and information across the membrane. Every membrane has a varying degree of protein content. Proteins can be in the form of peripheral or integral.

Table 3: types of protein molecules found in cell membrane

Type	Description	Examples
Integral proteins or *transmembrane proteins*	Span the membrane and have a hydrophilic cytosolic domain, which interacts with internal molecules, a hydrophobic membrane-spanning domain that anchors it within the cell membrane, and a hydrophilic extracellular domain that interacts with external molecules. The hydrophobic domain consists of one, multiple, or a combination of α-helices and β sheet protein motifs.	Ion channels, proton pumps, G protein-coupled receptor
Lipid anchored proteins	Covalently-bound to single or multiple lipid molecules; hydrophobically insert into the cell membrane and anchor the protein. The protein itself is not in contact with the membrane.	G proteins
Peripheral proteins	Attached to integral membrane proteins, or associated with peripheral regions of the lipid bilayer. These proteins tend to have only temporary interactions with biological membranes, and, once reacted the molecule, dissociates to carry on its work in the cytoplasm.	Some enzymes, some hormones

The cell membrane plays host to a large amount of protein that is responsible for its various activities. The amount of protein differs between species and according to function, however the typical amount in a cell membrane is 50%. These proteins are undoubtedly important to a cell: Approximately a third of the genes in yeast code specifically for them, and this number is even higher in multicellular organisms.

The cell membrane, being exposed to the outside environment, is an important site of cell-cell communication. As such, a large variety of protein receptors and identification proteins, such as antigens, are present on the surface of the membrane. Functions of membrane proteins can also include cell-cell contact, surface recognition, cytoskeleton contact, signaling, enzymatic activity, or transporting substances across the membrane.

Most membrane proteins must be inserted in some way into the membrane. For this to occur, an N-terminus "signal sequence" of amino acids directs proteins to the endoplasmic reticulum, which inserts the proteins into a lipid bilayer. Once inserted, the proteins are then transported to their final destination in vesicles, where the vesicle fuses with the target membrane.

3.10 Variation in membrane composition

The cell membrane has different lipid and protein compositions in distinct types of cells and may have therefore specific names for certain cell types:

- Sarcolemma in myocytes
- Oolemma in oocytes.

3.11 Membrane Permeability

The permeability of a membrane is the ease of molecules to pass through it. Permeability depends mainly on the electric charge of the molecule and to a lesser extent the molar mass of the molecule. Electrically neutral and small molecules pass the membrane easier than charged, large ones.

The inability of charged molecules to pass through the cell membrane results in pH parturition of substances throughout the fluid compartments of the body.

3.12 Functions of the Plasma Membrane

3.12.1 Cell Transport

The cell's plasma membrane does not simply form a "sack" in which to keep all the cytoplasm and other cellular organelles. The plasma membrane is a very important structure which functions to allow certain substances to enter or leave the cell. It can "pump" other substance into the cell against the concentration gradient or pump other "wastes" etc. out of the cell.

Some of the transport process happens "**passively**" without the cell needing to expend any energy to make them happen. These processes are called "**passive transport processes**".

Other transport processes require energy from the cell's reserves to "power" them. These processes are called "**active transport processes**".

3.12.2 Passive Transport Processes

a) **Diffusion**: definition - is the movement of ions or molecules from regions of **higher** concentration **to** regions of **lower** concentration. (**Down** a concentration gradient)

Passive processes - require no expenditure of energy by a cell:

- **Simple diffusion** = net movement of a substance from an area of high concentration to an area of low concentration. The rate of diffusion is influenced by:
    - concentration gradient
    - cross-sectional area through which diffusion occurs
    - temperature
    - molecular weight of a substance
    - distance through which diffusion occurs
- **Osmosis** = diffusion of water across a semipermeable membrane (like a cell membrane) from an area of low solute concentration to an area of high solute concentration (check rbl.cvmbs.colostate.edu/hbooks/cmb/cells/pmemb/osmosis.html for more information about osmosis)

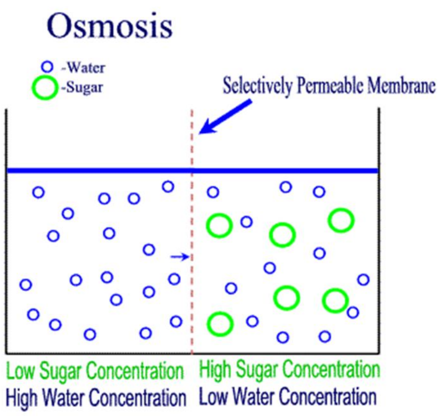


Fig 12: showing the role of cell membrane in nutrient transport

Facilitated diffusion = movement of a substance across a cell membrane from an area of high concentration to an area of low concentration. This process requires the use of 'carriers' (membrane proteins). In the example below, a ligand molecule (e.g., acetylcholine) binds to the membrane protein. This causes a conformational change or, in other words, an 'opening' in the protein through which a substance (e.g., sodium ions) can pass.

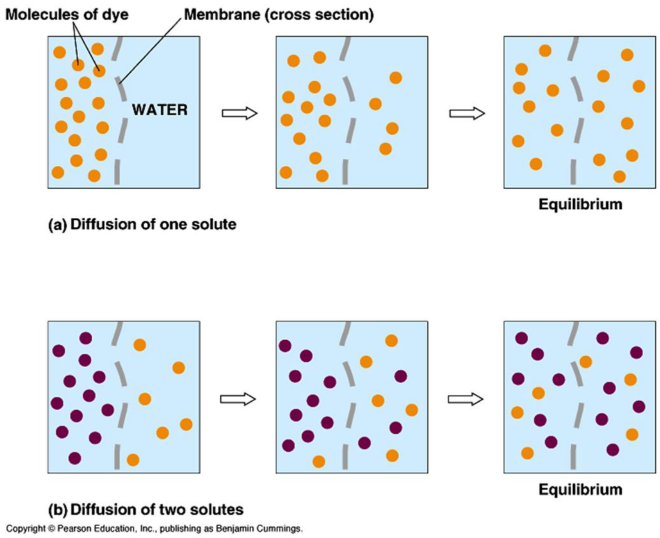


Fig 13: showing how diffusion of solutes pass across membran

3.12.3 Diffusion and the Plasma Membrane

The plasma membrane will allow certain substances to cross it but not others! Such a membrane is referred to as "**selective permeable**" (or "**semipermeable**"). The plasma membrane's permeability depends on a large part on its makeup.

Both the protein portion and the phospholipid portion of the membrane are involved in the permeability.

Molecules that pass through the phospholipid bilayer easily...

Hydrophobic molecules (oil soluble)	O_2, N_2
Nonpolar	Benzene
Small uncharged Polar molecules	H_2O, Urea, glycerol, CO_2

Molecules that don't pass through the phospholipid bilayer easily...

Large uncharged	Glucose
Polar molecules	Sucrose
Ions (charged)	H^+ , Na^+ , HCO_3 , K^+Ca^{2+} , Cl^- , Mg^{2+}

Therefore the three characteristics of a molecule that determine the permeability of the membrane to that species are . . .

1) Polarity - (Hydrophobic vs Hydrophylic)

2) Charge - (charged vs uncharged)

3) Size - (large vs small)

However: some molecules which we would think (from the above) should (or should not) cross the plasma membrane do - (or don't) **because** of the presence of the **membrane proteins**.

We shall see that these proteins in the membrane are involved in both **passive** and **active transport**.

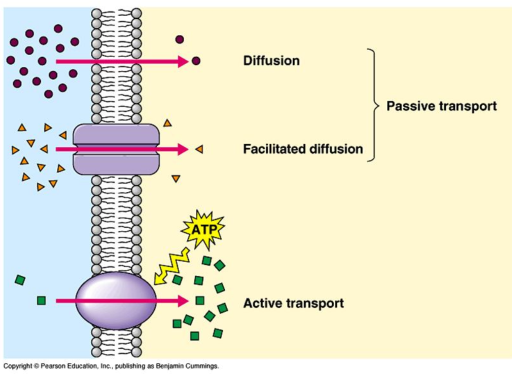


Fig 14: Osmosis: A special case - the diffusion of water through a cell membrane.

Definition: Osmosis is the movement of water from a region of high water concentration to a region of lower water concentration through a semi permeable membrane.

3.12.4 Active Transport

These are cell membrane processes that require energy. These processes are also (as far as we can tell) mediated by **membrane carrier molecule.** (Proteins)

"**Active Transport**" "pumps" materials across the membrane **against** the concentration gradient. I.e. **from low concentration to high concentration** therefore requires energy.

Active processes - require the expenditure of energy by cells:

- **Active transport** = movement of a substance across a cell membrane from an area of low concentration to an area of high concentration using a carrier molecule

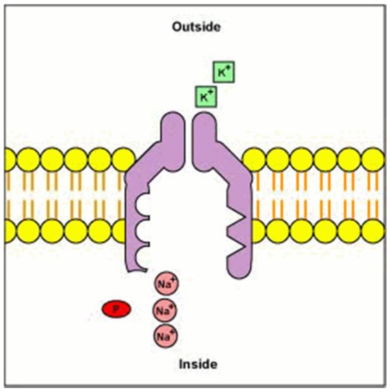


Fig 15: Active Transport: The Sodium-Potassium Pump

(Source: Gary Kaiser)

Endo- & exocytosis - moving material into (endo-) or out of (exo-) cell in bulk form

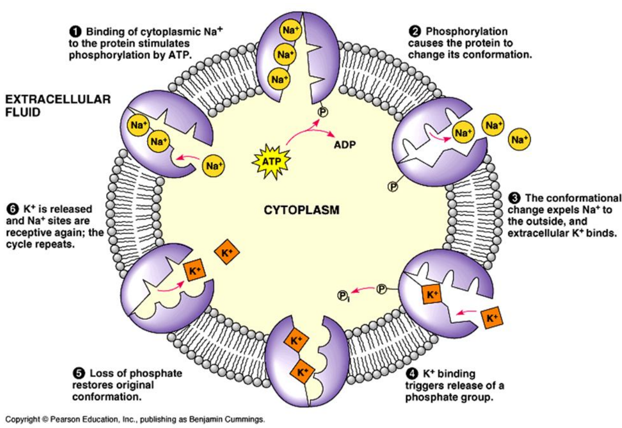
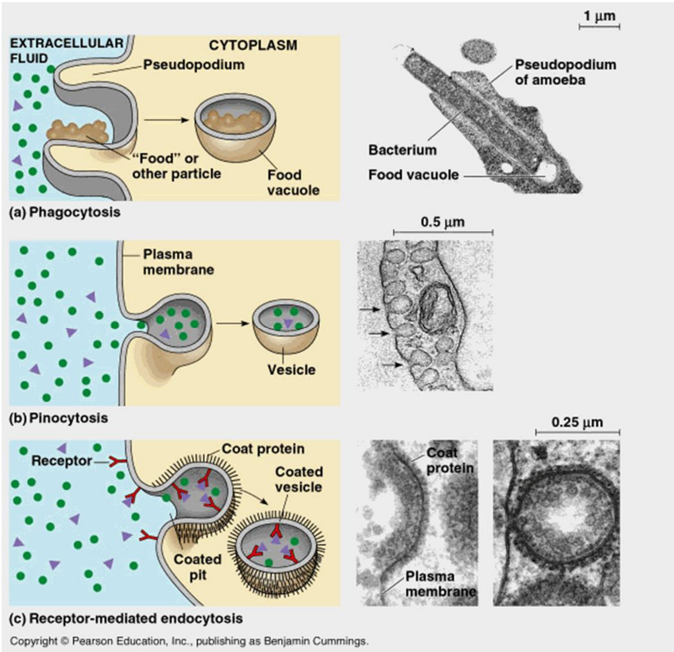


Fig 16a: showing how materials are move into and out of the cell through endo and exo-cytosis process

3.12.5 Other Energy Requiring Process

A. **Endocytosis**: Large materials transported into the cell.

Endocytosis includes three slightly different processes.



B. **Exocytosis**: Material (wastes etc.) are expelled from the cell (recall golgi vesicles).

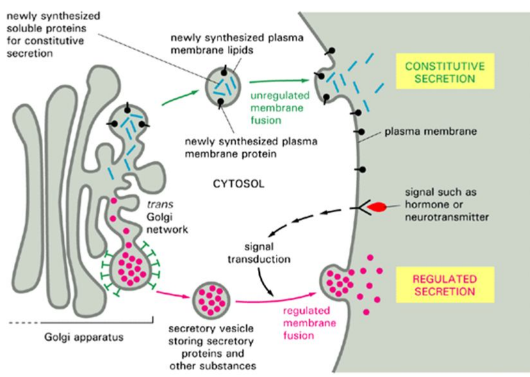


Fig 16b: showing how materials are move into and out of the cell through endo and exo-cytosis process

3.13 Animal Cells

Imagine we take a Red Blood Cell (RBC) which has an internal solute concentration of approximately 0.9% salt (equivalent) and place it in various solutions of varying salt and concentrations.

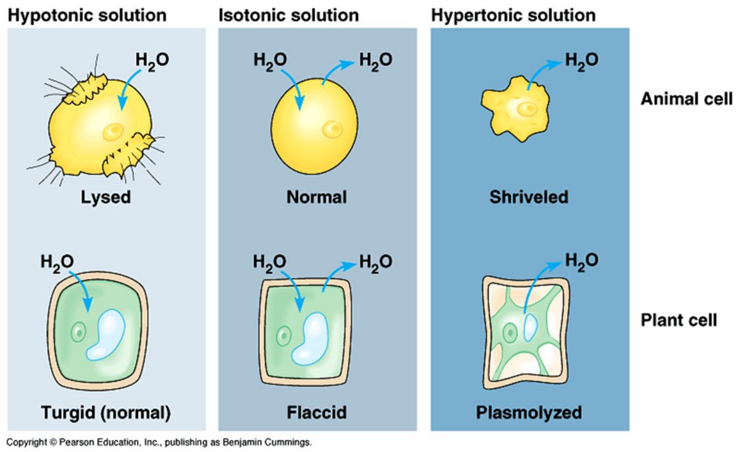


Fig 17: Osmosis: A special case - the diffusion of water through a cell membrane.

One can now describe the above cases using comparative terms:

"**Isotonic**"

"**Hypertonic**"

'**Hypotonic**"

Definition: the solution that loses the water is "**Hypotonic**" that solution that gains the water is "**Hypertonic**".

NB: One solution is **always** compared to the other solution.

i.e. the inside of the cell is "**Hypotonic**" to the outside if the cell (is cell shrinks). **Or**: the outside of the cell is "**Hypertonic**" to the inside (i.e. cell shrinks). etc.

Isotonic: Special equilibrium case where there is no net movement of water.

3.14 Plant Cell: "**Turgor Pressure**"

Plant cells have one extra structure surrounding it, that animal cells lack the '**cell wall**". If plant cells are exposed to the same conditions as the RBC's the osmotic reactions are the same but the cell wall prevents swelling and rupture.

Facilitated Diffusion

This is similar to simple diffusion in the sense that it is diffusion (across a membrane) from a high concentration to a lower concentration. **However**, this time the rate of diffusion is greatly accelerated by the action membrane proteins that act as carrier molecules and aid in diffusion. These "carrier proteins" are known as "**Permeases**".

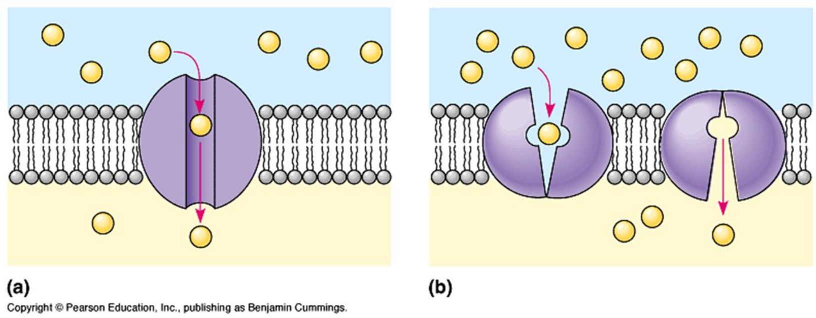


Fig 18: Protein Channels

Simple diffusion can also be accomplished by the passage of solutes through "tunnel-like" transmembrane proteins called channel proteins.

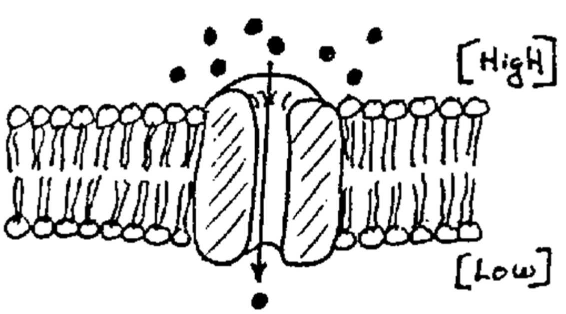


Fig 19: tunnel-like transmembrane channels

3.14 The Endomembrane System in Eukaryotic Cells

The cytoplasm of a cell is surrounded by a cell membrane or *plasma membrane*. The plasma membrane in plants and prokaryotes is usually covered by a cell wall. This membrane serves to separate and protect a cell from its surrounding environment and is made mostly from a double layer of lipids (hydrophobic fat-like molecules) and hydrophilic phosphorus molecules. Hence, the layer is called a phospholipid bilayer. It may also be called a fluid mosaic membrane. Embedded within this membrane is a variety of protein molecules that act as channels and pumps that move different molecules into and out of the cell. The membrane is said to be 'semi-permeable', in that it can either let a substance (molecule or ion) pass through freely, pass through to a limited extent or not pass through at all. Cell surface membranes also contain receptor proteins that allow cells to detect external signaling molecules such as hormones.

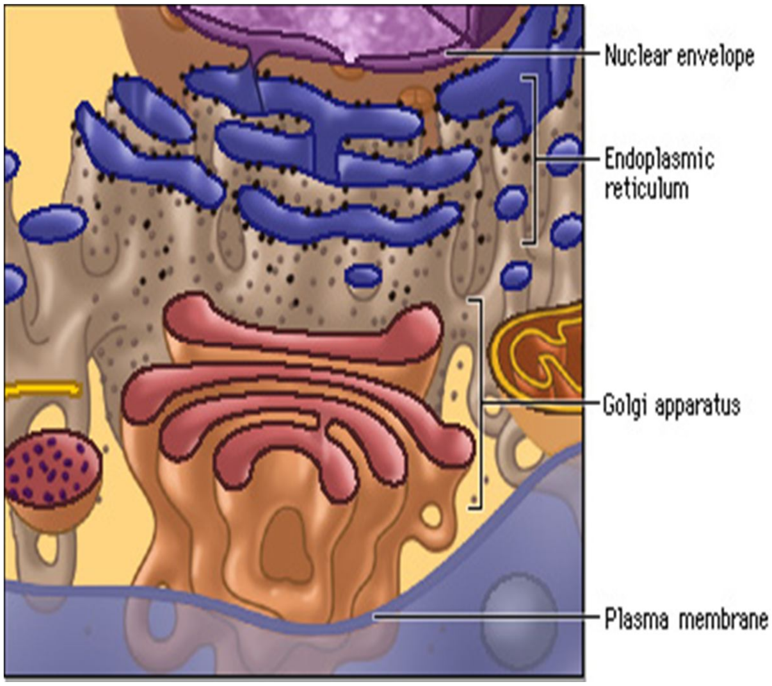


Fig 20: showing the membrane structure

3.14.1 Cytoskeleton

The cytoskeleton acts to organize and maintains the cell's shape; anchors organelles in place; helps during endocytosis, the uptake of external materials by a cell, and cytokinesis, the separation of daughter cells after cell division; and moves parts of the cell in processes of growth and mobility. The eukaryotic cytoskeleton is composed of microfilaments, intermediate filaments and microtubules. There is a great number of proteins associated with them, each controlling a cell's structure by directing, bundling, and aligning filaments. The prokaryotic cytoskeleton is less well-studied but is involved in the maintenance of cell shape, polarity and cytokinesis.[8]

3.14.2 Genetic material

Two different kinds of genetic material exist: deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). Most organisms use DNA for their long-term information storage, but some viruses (e.g., retroviruses) have RNA as their genetic material. The biological information contained in an organism is encoded in its DNA or RNA sequence. RNA is also used for information transport (e.g., mRNA) and enzymatic functions (e.g., ribosomal RNA) in organisms that use DNA for the genetic code itself. Transfer RNA (tRNA) molecules are used to add amino acids during protein translation.

Prokaryotic genetic material is organized in a simple circular DNA molecule (the bacterial chromosome) in the nucleoid region of the cytoplasm. Eukaryotic genetic material is divided into different, linear molecules called chromosomes inside a discrete nucleus, usually with additional genetic material in some organelles like mitochondria and chloroplasts (see endosymbiotic theory).

A human cell has genetic material contained in the cell nucleus (the nuclear genome) and in the mitochondria (the mitochondrial genome). In humans the nuclear genome is divided into 23 pairs of linear DNA molecules called chromosomes. The mitochondrial genome is a circular DNA molecule distinct from the nuclear DNA. Although the mitochondrial DNA is very small compared to nuclear chromosomes, it codes for 13 proteins involved in mitochondrial energy production and specific tRNAs.

Foreign genetic material (most commonly DNA) can also be artificially introduced into the cell by a process called transfection. This can be transient, if the DNA is not inserted into the cell's genome, or stable, if it is. Certain viruses also insert their genetic material into the genome.

UNIT 3: REGULATION OF INTRACELLULAR ENVIRONMENT, INTRACELLULAR ORGANELLES, THEIR BRIEF TREATMENT OF STRUCTURES AND FUNCTIONS

Contents

1.0 Introduction

This unit highlights on how the physiology of the inside of the cell is regulated and discusses to great level the structure and function of all the constituent organelles of a cell ranging from the cell membrane, the nucleus, the nuclear membrane, Golgi bodies and rest of them. The section also compares the role of organelles to that of the organ system found in metazoan.

2.0 Aim/objective

- To know the various organelles that make up the cell
- Know the various functions/roles played by the various cell organelles for instance knowing where the energy factories etc are located
- and how the cell behaves in terms of reproduction, response and cellular metabolism

3.0 Main Text

3.1 Components of the Cellular Environment

3.1.1 Water:

Water comprises 60 - 90% of most living organisms (and cells). It is important because it serves as an excellent solvent and enters into many metabolic reactions.

3.1.2 Ions

Atoms or molecules with unequal numbers of electrons and protons: These are found in both intra- and extracellular fluid. Examples of important ions include sodium, potassium, calcium, and chloride.

3.1.3 Carbohydrates:

These form about 3% of the dry mass of a typical cell. They composed of carbon, hydrogen, & oxygen atoms (e.g., glucose is $C6H12O6$). Carbohydrates are an important source of energy for cells.

Carbohydrates are of different types including:

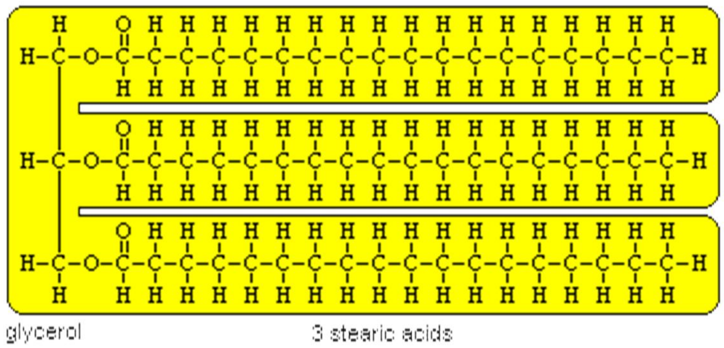
I. monosaccharides (e.g., glucose) - most contain 5 or 6 carbon atoms
II. disaccharides 2 monosaccharides linked together examples include sucrose (a common plant disaccharide is composed of the monosaccharides glucose and fructose) and lactose (or milk sugar; a disaccharide composed of glucose and the monosaccharide galactose)
III. polysaccharides several monosaccharides linked together examples include starch (a common plant polysaccharide made up of many glucose molecules) and glycogen (commonly stored in the liver)

3.1.4 Lipids:

Lipids form about 40% of the dry mass of a typical cell. They composed largely of carbon & hydrogen. They are generally insoluble in water. Lipids are involved mainly with long-term energy storage; other functions are as structural components (as in the case of phospholipids that are the major building block in cell membranes) and as "messengers" (hormones) that play roles in communications within and between cells are performed by lipids.

Lipids Subclasses include:

i. triglycerides - consist of one glycerol molecule + 3 fatty acids (e.g., stearic acid in the diagram below). Fatty acids typically consist of chains of 16 or 18 carbons (plus lots of hydrogens).



ii. phospholipids - a phosphate group (-PO4) substitutes for one fatty acid & these lipids are an important component of cell membranes

iii. steroids - include testosterone, estrogen, & cholesterol

Fig 21: structure of lipid sub class

3.1.5 Proteins

A typical cell contain about 50 - 60% protein of the dry mass. The subunit is the amino acid which is linked by peptide bonds

There are 2 functional categories of proteins

i. structural (proteins part of the structure of a cell like those in the cell membrane)

ii. ii. Enzymes. Enzymes are catalysts. Enzymes bind temporarily to one or more of the reactants of the reaction they catalyze. In doing so, they lower the amount of activation energy needed and thus speed up the reaction.

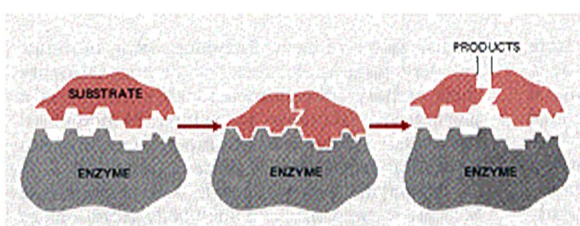


Fig 22: forms of proteins
Used by permission of John W. Kimball

3.1.6 Nucleic Acids

The nucleic acid of cell membrane is of two types; DNA and RNA (including mRNA, tRNA and rRNA).

3.2 Sub-cellular components

All cells, whether prokaryotic or eukaryotic, have a membrane that envelops the cell, separates its interior from its environment, regulates what moves in and out (selectively permeable), and maintains the electric potential of the cell. Inside the membrane, a salty cytoplasm takes up most of the cell volume. All cells possess DNA, the hereditary material of genes, and RNA, containing the information necessary to build various proteins such as enzymes, the cell's primary machinery. There are also other kinds of biomolecules in cells. This material will list these primary components of the cell, and then briefly describe their function.

3.2.1 Membrane

The cytoplasm of a cell is surrounded by a cell membrane or *plasma membrane*. The plasma membrane in plants and prokaryotes is usually covered by a cell wall. This membrane serves to separate and protect a cell from its surrounding environment and is made mostly from a double layer of lipids (hydrophobic fat-like molecules) and hydrophilic phosphorus molecules. Hence, the layer is called a phospholipid bilayer. It may also be called a fluid mosaic membrane. Embedded within this membrane is a variety of protein molecules that act as channels and pumps that move different molecules into and out of the cell. The membrane is said to be 'semi-permeable', in that it can either let a substance (molecule or ion) pass through freely, pass through to a limited extent or not pass through at all. Cell surface membranes also contain receptor proteins that allow cells to detect external signaling molecules such as hormones.

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3.3 Cell and its constituent organelles

The human body contains many different organs, such as the heart, lung, and kidney, with each organ performing a different function. Cells also have a set of "little organs," called organelles, these organelles are adapted and/or specialized for carrying out one or more vital functions. Both eukaryotic and prokaryotic cells have organelles but organelles in eukaryotes are generally more complex and may be membrane bound. Organelles are found inside the protoplasm of the cell in the cytosol (a gelatinous fluid that fills the cell and surrounds the organelles).

There are several types of organelles in a cell. Some (such as the nucleus and golgi apparatus) are typically solitary, while others (such as mitochondria, peroxisomes and lysosomes) can be numerous (hundreds to thousands).

3.3.1 They cytoplasm

Cytoplasm consists of a gelatinous solution (cystosol) and contains microtubules (which serve as a cell's cytoskeleton) and organelles (literally referred to as “little organs’’)

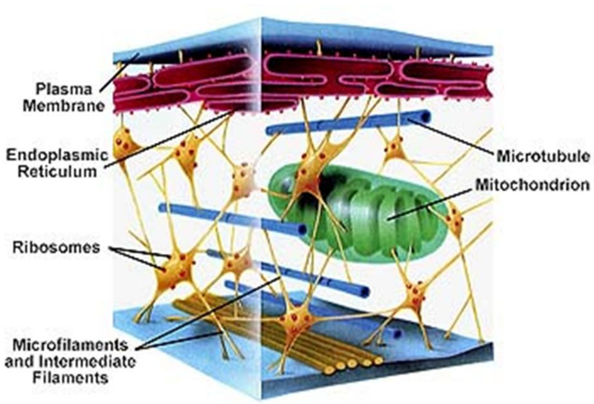


Fig 23: structure of cytoplasm showing various organelles it contains

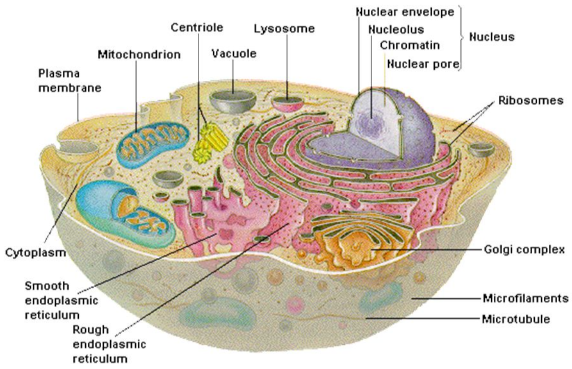


Fig 24: showing some organelles that are bounded by the cell membrane

3.3.2 The Nucleus

This is the cell's information center. Only Eukaryotic cells contain a nucleus within which is found DNA (deoxyribonucleic acid) in the form of chromosomes plus nucleoli (within which ribosomes are formed). The nucleus is lacking in the prokaryotic cells.

The cell nucleus is the most conspicuous organelle found in a eukaryotic cell. It houses the cell's chromosomes, and is the place where almost all DNA replication and RNA synthesis (transcription) occur. The nucleus is spherical and separated from the cytoplasm by a double membrane called the nuclear envelope. The nucleus is the hallmark of eukaryotic cells; the very term eukaryotic means having a "true nucleus". The nucleus is enveloped by a pair of membranes enclosing a lumen that is continuous with that of the endoplasmic reticulum. This membrane is called the nuclear envelop. The nuclear envelope is perforated by thousands of **nuclear pore complexes** (**NPC**s) that control the passage of molecules in and out of the nucleus. The nuclear envelope isolates and protects a cell's DNA from various molecules that could accidentally damage its structure or interfere with its processing. During processing, DNA is transcribed, or copied into a special RNA, called messenger RNA (mRNA). This mRNA is then transported out of the nucleus, where it is translated into a specific protein molecule.

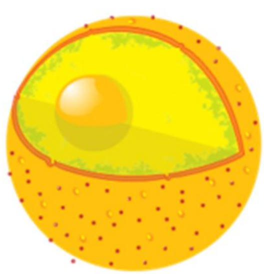


Fig 25: Diagram of the cell nucleus

The nucleus regulates all cell activity. It does this by controlling the enzymes present. The chromatin is composed of DNA. DNA contains the information for the production of proteins. This information is encoded in the 4 DNA bases. Adenine, thymine, cytocine, and guanine. The specific sequence of these bases tells the cell what order to put the amino acids. There are three processes that enable the cell to manufacture protein:

i. Replication allows the nucleus to make exact copies of its DNA

iii. Transcription allows the cell to make RNA working copies of its DNA

iv. In translation the Messenger RNA is used to line up amino acids into a protein molecule.

The nucleolus is a specialized region within the nucleus where ribosome subunits are assembled. In prokaryotes, DNA processing takes place in the cytoplasm.

3.3.3 Chromatin

The nucleus contains the chromosomes of the cell. Each chromosome consists of a single molecule of DNA complexed with an equal mass of proteins. Collectively, the DNA of the nucleus with its associated proteins is called **chromatin**. Chromatin also contains small amounts of a wide variety of **nonhistone proteins**. Most of these are transcription factors (e.g., the steroid receptors) and their association with the DNA is more transient.

Most of the protein in the nucleus consists of multiple copies of 5 kinds of **histones**. These are basic proteins, bristling with positively charged arginine and lysine residues. (Both Arg and Lys have a free amino group on their R group, which attracts protons (H^+) giving them a positive charge.) Just the choice of amino acids you would make to bind tightly to the negatively-charged phosphate groups of DNA.

3.3.4 Nucleosomes and Transcription

Transcription factors cannot bind to their promoter if the promoter is blocked by a nucleosome. One of the first functions of the assembling transcription factors is to either expel the nucleosome from the site where transcription begins or at least to slide the nucleosomes along the DNA molecule. Either action exposes the gene's promoter so that the transcription factors can then bind to it.

The actual transcription of protein-coding genes is done by RNA polymerase II (RNAP II). In order for it to travel along the DNA to be transcribed, a complex of proteins removes the nucleosomes in front of it and then replaces them after RNAP II has transcribed that portion of DNA and moved on.

3.3.5 The Nucleolus

The nucleolus is a specialized region within the nucleus where ribosome subunits are assembled. In prokaryotes, DNA processing takes place in the cytoplasm. During the period between cell divisions, when the chromosomes are in their extended state, one or more of them (10 in human cells) have loops extending into a spherical mass called the nucleolus. Here are synthesized three (of the four) kinds of RNA molecules (28S, 18S, 5.8S) used in the assembly of the large and small subunits of **ribosomes**.

28S, 18S, and 5.8S ribosomal RNA is transcribed (by RNA polymerase I) from hundreds to thousands of tandemly-arranged **rDNA genes** distributed (in humans) on 10 different chromosomes. The rDNA-containing regions of these 10 chromosomes cluster together in the nucleolus. (In yeast, the 5S rRNA molecules — as well as transfer RNA molecules — are also synthesized (by RNA polymerase III) in the nucleolus.)

Once formed, rRNA molecules associate with the dozens of different ribosomal **proteins** used in the assembly of the large and small subunits of the ribosome.

But proteins are synthesized in the cytosol — and all the ribosomes are needed in the cytosol to do their work — so there must be a mechanism for the transport of these large structures in and out of the nucleus. This is one of the functions of the nuclear pore complexes.

3.3.6 Nuclear Pore Complexes (NPCs)

The nuclear envelope is perforated with thousands of pores.

Each is constructed from a number (30 in yeast; probably around 50 in vertebrates) different protein called **nucleoporins**.

The entire assembly forms an aqueous channel connecting the cytosol with the interior of the nucleus ("nucleoplasm"). When materials are to be transported through the pore, it opens up to form a channel some 25 nm wide — large enough to get such large assemblies as ribosomal subunits through.

Transport through the nuclear pore complexes is **active**; that is, it requires

- energy
- many different carrier molecules each specialized to transport a particular cargo
- docking molecules in the NPC (represented here as colored rods and disks).

3.3.7 Import into the nucleus

Proteins are synthesized in the cytosol and those needed by the nucleus must be imported into it through the NPCs.

They include:

- all the **histones** needed to make the nucleosomes
- all the **ribosomal proteins** needed for the assembly of ribosomes
- all the **transcription factors** (e.g., the steroid receptors) needed to turn genes on (and off)
- all the **splicing factors** needed to process pre-mRNA into mature mRNA molecules; that is, to cut out intron regions and splice the exon regions.

Probably all of these proteins has a characteristic sequence of amino acids — called a **nuclear localization sequence** (NLS) — that target them for entry.

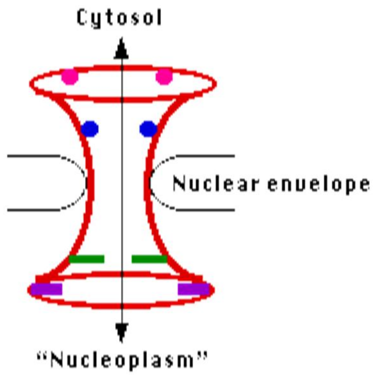


Fig 26: The nuclear

3.3.8 Export from the nucleus

Molecules and macromolecular assemblies exported from the nucleus include:

- the **ribosomal subunits** containing both rRNA and proteins
- **messenger RNA** (mRNA) molecules (accompanied by proteins)
- **transfer RNA** (tRNA) molecules (also accompanied by proteins)
- **transcription factors** that are returned to the cytosol to await reuse

Both the RNA and protein molecules contain a characteristic **nuclear export sequence** (NES) needed to ensure their association with the right carrier molecules to take them out to the cytosol.

3.3.9 Mitochondria and Chloroplasts

Only found in eukaryotes. They are the power generators. Mitochondria are self-replicating organelles that occur in various numbers, shapes, and sizes in the cytoplasm of all eukaryotic cells. They have a double-membrane: one outer membrane and a second highly convoluted inner membrane
Mitochondria play a critical role in generating energy in the eukaryotic cell. Mitochondria generate the cell's energy by oxidative phosphorylation, using oxygen to release energy stored in cellular nutrients (typically pertaining to glucose) to generate ATP. Mitochondria multiply by splitting in two. Respiration occurs in the cell mitochondria.
Organelles that are modified chloroplasts are broadly called plastids, and are involved in energy storage through photosynthesis, which uses solar energy to generate carbohydrates and oxygen from carbon dioxide and water.

Mitochondria and chloroplasts each contain their own genome, which is separate and distinct from the nuclear genome of a cell. Both organelles contain this DNA in circular plasmids, much like prokaryotic cells, strongly supporting the evolutionary theory of endosymbiosis; since these organelles contain their own genomes and have other similarities to prokaryotes, they are thought to have developed through a symbiotic relationship after being engulfed by a primitive cell.

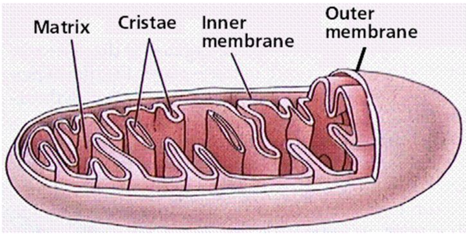


Fig 27: Mitochondria showing inner membrane with folds or shelf-like structures called cristae that contain elementary particles; these particles contain enzymes important in ATP production. Primary function of mitochondria is production of adenosine triphosphate (ATP)

3.3.10 Golgi apparatus

Only present in eukaryotes. Golgi apparatus consists of a series of flattened sacs (or cisternae). It has a structure that is made up of cisternae, which are flattened stacks of membrane usually found in a series of five to eight. The function of the Golgi apparatus is to modify, sort, and package proteins and other materials from the endoplasmic reticulum for storage in the cell or secretion outside the cell.

Fig 28: Diagram of Golgi body showing an endomembrane system

The main function of the Golgi apparatus is to be responsible for handling the macromolecules that are required for proper cell functioning. It processes and packages these macromolecules for use within the cell or for secretion. Primarily, the Golgi apparatus modifies proteins that it receives from the rough endoplasmic reticulum, however, it also transports lipids to vital parts of the cell and creates lysosomes. These cisternae help proteins travel from different points in the cell using enzymes. In order to modify a macromolecule, cisternae's enzymes need the addition of carbohydrates and phosphates to properly label each protein for its ultimate destination. These carbohydrates and phosphates are received by the Golgi apparatus through nucleotide sugars delivered to the organelle from the cytosol.

How the proteins and vesicles pass through the Golgi apparatus structure is unclear, however, there are theories regarding the subject. According to the vesicular transport model, there are a variety of compartments located between the cis, essentially the beginning of the Golgi apparatus, and the Trans. These compartments shuttle along the macromolecules from section to section using membrane-bound carriers. The cisternal maturation model states that the vesicles fuse to each other at the cis face of the Golgi apparatus and are essentially pushed along as new vesicles fuse together behind them.

Other functions of the Golgi apparatus include the production of glycosaminoglycans, which go on to form parts of connective tissues. The Golgi will use a xylose link to polymerize the glycosaminoglycans onto proteins to form proteoglycan.

It then performs sulfation onto the proteoglycans in order to aid in signaling abilities and giving the molecule a negative charge.

The Bcl-2 genes that are located within the Golgi apparatus also play a significant role in preventing apoptosis, or the destruction of the cell.

As part of eukaryotic cells, the Golgi apparatus works in unison with the endomembrane system.

3.3.11 Ribosomes

A **ribosome** is the component of a biological cell that creates proteins from all amino acids and RNA representing the protein. One of the central tenets of biology, often referred to as the central dogma of molecular biology, is that DNA is used to make RNA, which is used to make protein. The DNA sequence in genes is copied into a messenger RNA (mRNA). Ribosomes then read the information in this RNA and use it to create proteins. This process is known as translation; the ribosome translates the genetic information from RNA into proteins. Ribosomes do this by binding to an mRNA and using it as a template for the correct sequence of amino acids in a particular protein. The amino acids are attached to transfer RNA (tRNA) molecules, which enter one part of the ribosome and bind to the messenger RNA sequence. The attached amino acids are then joined together by another part of the ribosome. The ribosome moves along the mRNA, "reading" its sequence and producing a chain of amino acids.

Ribosomes are made from complexes of RNAs and proteins. Ribosomes are divided into two subunits. The smaller subunit binds to the mRNA, while the larger subunit binds to the tRNA and the amino acids. When a ribosome finishes reading a mRNA, these two subunits split apart. Ribosomes have been classified as ribozymes, because the ribosomal RNA seems to be most important for the peptidyl transferase activity that links amino acids together.

Ribosomes from bacteria, archaea and eukaryotes (the three domains of life on Earth) have significantly different structures and RNA sequences. These differences in structure allow some antibiotics to kill bacteria by inhibiting their ribosomes, while leaving human ribosomes unaffected. The ribosomes in the mitochondria of eukaryotic cells resemble those in bacteria, reflecting the likely evolutionary origin of this organelle. The word ribosome comes from *ribo*nucleic acid and the Greek: *soma* (meaning body).

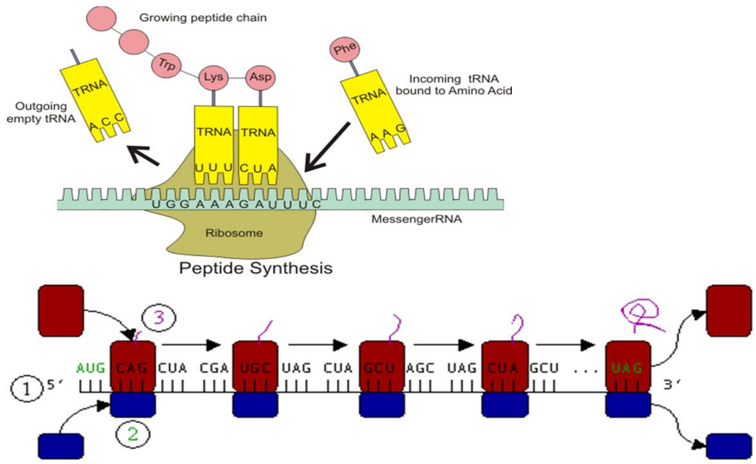


Fig 29: Ribosome peptide synthesis

3.3.12 Lysosomes and Peroxisomes

Only present in eukaryotes. Lysosomes contain digestive enzymes (acid hydrolases). They digest excess or worn-out organelles, food particles, and engulfed viruses or bacteria. Peroxisomes have enzymes that rid the cell of toxic peroxides. The cell could not house these destructive enzymes if they were not contained in a membrane-bound system. These organelles are often called a "suicide bag" because of their ability to detonate and destroy the cell.

3.3.13 Centrosome – the cytoskeleton organizer

The centrosome produces the microtubules of a cell – a key component of the cytoskeleton. It directs the transport through the ER and the Golgi apparatus. Centrosomes are composed of two centrioles, which separate during cell division and help in the formation of the mitotic spindle. A single centrosome is present in the animal cells. They are also found in some fungi and algae cells.

3.3.14 Vacuoles

Vacuoles store food and waste. Some vacuoles store extra water. They are often described as liquid filled space and are surrounded by a membrane. Some cells, most notably *Amoeba*, have contractile vacuoles, which can pump water out of the cell if there is too much water. The vacuoles of eukaryotic cells are usually larger in those of plants than animals.

3.3.15 Centrioles

Paired cylindrical structures located near the nucleus. Play an important role in cell division

3.3.16 Endoplasmic reticulum (smooth and rough)

The **endoplasmic reticulum** (**ER**) is a eukaryotic organelle that forms an interconnected network of tubules, vesicles, and cisternae within cells. **Rough endoplasmic reticula** synthesize proteins, while **smooth endoplasmic reticula** synthesize lipids and steroids, metabolize carbohydrates and steroids (but not lipids), and regulate calcium concentration, drug metabolism, and attachment of receptors on cell membrane proteins. **Sarcoplasmic reticula** solely regulate calcium levels.

Structure of Endoplasmic Membrane

The general structure of the endoplasmic reticulum is an extensive membrane network of cisternae (sac-like structures) held together by the cytoskeleton. The phospholipid membrane encloses a space, the cisternal space (or lumen), which is continuous with the perinuclear space but separate from the cytosol. The functions of the endoplasmic reticulum vary greatly depending on the exact type of endoplasmic reticulum and the type of cell in which it resides. The three varieties are called *rough endoplasmic reticulum, smooth endoplasmic reticulum* and *sarcoplasmic reticulum*.

The quantity of RER and SER in a cell can quickly interchange from one type to the other, depending on changing metabolic needs: one type will undergo numerous changes including new proteins embedded in the membranes in order to transform. Also, massive changes in the protein content can occur without any noticeable structural changes, depending on the enzymatic needs of the cell (as per the functions listed below).

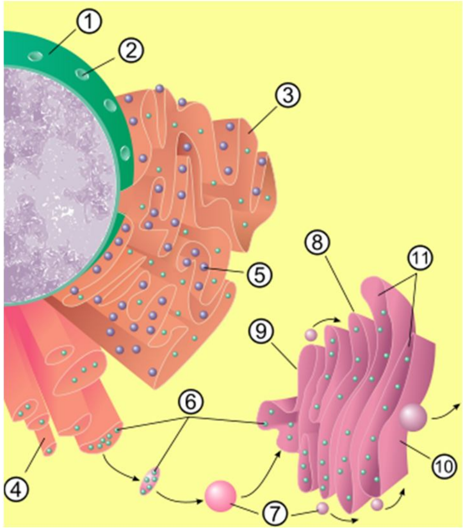


Fig 30: Cross section of the cell showing Rough and Smooth endoplasmic reticulum on numbers 3 and 4 respectively

1 *Nucleus* ***2*** *Nuclear pore* ***3*** *Rough endoplasmic reticulum (RER)* ***4*** *Smooth endoplasmic reticulum (SER)* ***5*** *Ribosome on the rough ER* ***6*** *Proteins that are transported* ***7*** *Transport vesicle* ***8*** *Golgi apparatus* ***9*** *Cis face of the Golgi apparatus* ***10*** *Trans face of the Golgi apparatus* ***11*** *Cisternae of the Golgi apparatus*

Rough endoplasmic reticulum

The surface of the rough endoplasmic reticulum (RER) is studded with protein-manufacturing ribosomes giving it a "rough" appearance (hence its name). However, the ribosomes bound to the RER at any one time are not a stable part of this organelle's structure as ribosomes are constantly being bound and released from the membrane. A ribosome only binds to the ER once it begins to synthesize a protein destined for the secretory pathway. Here, a ribosome in the cytosol begins synthesizing a protein until a signal recognition particle recognizes the pre-piece of 5-15 hydrophobic amino acids preceded by a positively charged amino acid. This signal sequence allows the recognition particle to bind to the ribosome, causing the ribosome to bind to the RER and pass the new protein through the ER membrane. The pre-piece is then cleaved off within the lumen of the ER and the ribosome released back into the cytosol.

The membrane of the RER is continuous with the outer layer of the nuclear envelope. Although there is no continuous membrane between the RER and the Golgi apparatus, membrane-bound vesicles shuttle proteins between these two compartments. Vesicles are surrounded by coating proteins called COPI and COPII. COPII targets vesicles to the golgi and COPI marks them to be brought back to the RER. The RER works in concert with the Golgi complex to target new proteins to their proper destinations. A second method of transport out of the ER are areas called membrane contact sites, where the membranes of the ER and other organelles are held closely together, allowing the transfer of lipids and other small molecules.

The RER is a key in multiple functions:

- lysosomal enzymes with a mannose-6-phosphate marker added in the *cis*-Golgi network
- Secreted proteins, either secreted constitutively with no tag, or regulated secretion involving clathrin and paired basic amino acids in the signal peptide.
- integral membrane proteins that stay imbedded in the membrane as vesicles exit and bind to new membranes. Rab proteins are key in targeting the membrane, SNAP and SNARE proteins are key in the fusion event.
- initial glycosylation as assembly continues. This is either N-linked (O-linking occur in the golgi).
    - N-linked glycosylation: if the protein is properly folded, glycosyltransferase recognizes the AA sequence NXS or NXT (with the S/T residue phosphorylated) and adds a 14 sugar backbone (2 *N*-acetylglucosamine, 9 branching mannose, and 3 glucose at the end) to the side chain nitrogen of Asn

Smooth endoplasmic reticulum

The smooth endoplasmic reticulum (SER) has functions in several metabolic processes, including synthesis of lipids and steroids, metabolism of carbohydrates, regulation of calcium concentration, drug detoxification, attachment of receptors on cell membrane proteins, and steroid metabolism. It is connected to the nuclear envelope. Smooth endoplasmic reticulum is found in a variety of cell types (both animal and plant) and it serves different functions in each. The Smooth ER also contains the enzyme glucose-6-phosphatase which converts glucose-6-phosphate to glucose, a step in gluconeogenesis. The SER consists of tubules and vesicles that branch forming a network. In some cells there are dilated areas like the sacs of RER. The network of SER allows increased surface area for the action or storage of key enzymes and the products of these enzymes.

Sarcoplasmic reticulum

The sarcoplasmic reticulum (SR), from the Greek *sarx*, ("flesh"), is a special type of smooth ER found in smooth and striated muscle. The only structural difference between this organelle and the SER is the medley of proteins they have, both bound to their membranes and drifting within the confines of their lumens. This fundamental difference is indicative of their functions: the SER synthesizes molecules while the SR stores and pumps calcium ions. The SR contains large stores of calcium, which it sequesters and then releases when the muscle cell is stimulated. The SR's release of calcium upon electrical stimulation of the cell plays a major role in excitation-contraction coupling.

Functions of the endoplasmic reticulum

The endoplasmic reticulum serves many general functions, including;

i. the facilitation of protein folding and the transport of synthesized proteins in sacs called cisternae.
ii. Correct folding of newly-made proteins is made possible by several endoplasmic reticulum chaperone proteins, including protein disulfide isomerase (PDI), ERp29, the Hsp70 family member Grp78, calnexin, calreticulin, and the peptidylpropyl isomerase family. Only properly-folded proteins are transported from the rough ER to the Golgi complex.
iii. Transport of proteins: Secretory proteins, mostly glycoproteins, are moved across the endoplasmic reticulum membrane. Proteins that are transported by the endoplasmic reticulum and from there throughout the cell are marked with an address tag called a signal sequence. The N-terminus (one end) of a polypeptide chain (i.e., a protein) contains a few amino acids that work as an address tag, which are removed when the polypeptide reaches its destination. Proteins that are destined for places outside the endoplasmic reticulum are packed into transport vesicles and moved along the cytoskeleton toward their destination.
iv. The endoplasmic reticulum is also part of a protein sorting pathway. It is, in essence, the transportation system of the eukaryotic cell. The majority of endoplasmic reticulum resident proteins are retained in the endoplasmic reticulum through a retention motif. This motif is composed of four amino acids at the end of the protein sequence. The most common retention sequence is KDEL (*lys-asp-glu-leu*). However, variation on KDEL does occur and other sequences can also give rise to endoplasmic reticulum retention. It is not known if such variation can lead to sub-endoplasmic reticulum localizations. There are three KDEL receptors in mammalian cells, and they have a very high degree of sequence identity. The functional differences between these receptors remain to be established.

Other functions

v. **Insertion of proteins into the endoplasmic reticulum membrane:** Integral membrane proteins are inserted into the endoplasmic reticulum membrane as they are being synthesized (co-translational translocation). Insertion into the endoplasmic reticulum membrane requires the correct topogenic signal sequences in the protein.
vi. **Glycosylation**: Glycosylation involves the attachment of oligosaccharides.
vii. **Disulfide bond formation and rearrangement**: Disulfide bonds stabilize the tertiary and quaternary structure of many proteins.
viii. **Drug metabolism**: The smooth ER is the site at which some drugs are modified by microsomal enzymes which include the cytochrome P450 enzymes.

3.3.17 Cytoplasm/protoplasm

Protoplasm

The word 'protoplasm' comes from the Greek *protos* for *first*, and *plasma* for *thing formed*. It was first used in 1846 by Hugo von Mohl to describe the "tough, slimy, granular, semi-fluid" substance within plant cells, to distinguish this from the cell wall, cell nucleus and the cell sap within the vacuole. Thomas Huxley later referred to it as the "physical basis of life" and considered that the property of life resulted from the distribution of molecules within this substance.

The idea that protoplasm is divisible into a ground substance called "cytoplasm" and a structural body called the cell nucleus reflects the more primitive knowledge of cell structure that preceded the development of electron microscopy, when it seemed that cytoplasm was a homogeneous fluid and the existence of most sub-cellular compartments, or how cells maintain their shape, was unknown. Today, it is known that the cell contents are structurally very complex and contain multiple organelles.

Protoplasm is the living content of a cell that is surrounded by a plasma membrane (cell membrane). Protoplasm is composed of a mixture of;

i) Small molecules such as: ions, amino acids, monosaccharides and water,

ii) Macromolecules such as: nucleic acids, proteins, lipids and polysaccharides.

In eukaryotes the protoplasm surrounding the cell nucleus is known as the cytoplasm and that inside the nucleus is the nucleoplasm.

In prokaryotes the material inside the plasma membrane is the bacterial cytoplasm, while in gram-negative bacteria the region outside the plasma membrane but inside the outer membrane is the periplasm.

Protoplasm is distinct from non-living cell components lumped under substances such as inclusion bodies, although these substances can occur in the protoplasm. In many plant cells most of the volume of the cell is not occupied by protoplasm, but by "tonoplast", a large water filled vacuole enclosed by a membrane. A protoplast is a plant or fungal cell that has had its cell wall removed.

Physical properties of protoplasm

It is a transparent and jelly-like material, the consistency varying from the more liquid, slightly gelatinous white of a fresh egg to that of semi-solidified gelatin of jelly. If the protoplasm is more liquid it is termed a **sol**, if more gelatinous, a **gel**.

Chemical properties of protoplasm

The chemical properties of protoplasm can be divided into inorganic and organic substances.

Inorganic Substances: Inorganic substances are water, which make up 90% of the protoplasm, mineral salts, such as NaCl-salt, and gases like oxygen and carbon dioxide.

Organic Substances: Organic substances include proteins, carbohydrates, lipids, nucleic acids and enzymes.

Functions of the Protoplasm

i. **Reproduction** Cells divide to form identical daughter cells; function of the nucleus of the protoplasm, e.g. the meristematic region of angiosperms.
ii. **Irritability** The living protoplasm responds to stimuli, e.g. retinal cells in the eye respond to light.
iii. **Chemical** All these functions are carried out inside the cell, e.g. respiration in the mitochondria;
iv. **Excretion** Cells must get rid of excretory wastes; they usually diffuse out of the cell through the cell membrane.
v. **Movement:** Movement is exhibited by certain cells, e.g. unicells; the protoplasm of these cells has a contractile ability.
vi. **Growth:** Growth follows on cell division; there is an assimilation of protoplasm and an increase in size.

Cytoplasm

The cytoplasm is a thick liquid residing between the cell membrane holding all organelles, except for the nucleus. All the contents of the cells of prokaryote organisms (which lack a cell nucleus) are contained within the cytoplasm. Within the cells of eukaryote organisms the contents of the cell nucleus are separated from the cytoplasm, and are then called the nucleoplasm.
In eukaryotic cells also, the cytoplasm contains organelles, such as mitochondria, which are filled with liquid that is kept separate from the rest of the cytoplasm by biological membranes. It is within the cytoplasm that most cellular activities occur, such as many metabolic pathways including glycolysis, and processes such as cell division. The inner, granular mass is called the endoplasm and the outer, clear and glassy layer is called the cell cortex or the ectoplasm.
The part of the cytoplasm that is not held within organelles is called the cytosol. The cytosol is a complex mixture of cytoskeleton filaments, dissolved molecules, and water that fills much of the volume of a cell. The cytosol is a gel, with a network of fibers dispersed through water. Due to this network of pores and high concentrations of dissolved macromolecules, such as proteins, an effect called macromolecular crowding occurs and the cytosol does not act as an ideal solution. This crowding effect alters how the components of the cytosol interact with each other.
Movement of calcium ions in and out of the cytoplasm is thought to be a signaling activity for metabolic processes.

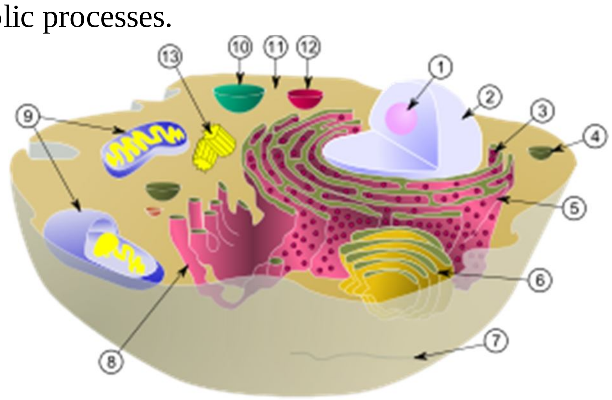


Fig 31: Schematic diagram showing the cytoplasm, with major components (organelles) of a typical animal cell.
(3) ribosomes (indicated by purple dots)
(4) vesicle

(5) rough endoplasmic reticulum (ER)
(6) Golgi apparatus
(7) cytoskeleton
(8) smooth ER
(9) mitochondria
(10) vacuole
(11) cytosol
(12) lysosome
(13) centrioles within centrosome

Constituents of the cytoplasm

The cytoplasm has three major elements; the cytosol, organelles and inclusions.

Cytosol

The cytosol is the portion not within membrane-bound organelles. The cytosol is a translucent fluid in which the plasmic elements are suspended. Cytosol makes up about 70% of the cell volume and is composed of water, salts and organic molecules. The cytoplasm also contains the protein filaments that make up the cytoskeleton, as well as soluble proteins and small structures such as ribosomes, proteasomes, and the mysterious vault complexes. The inner, granular and more fluid portion of the cytoplasm is referred to as endoplasm.

Organelles

Organelles are membrane-bound "organs" inside the cell that have specific functions. Some major organelles that are suspended in the cytosol are the mitochondria, the endoplasmic reticulum, the Golgi apparatus, vacuoles, lysosomes, and in plant cells chloroplasts.

Cytoplasmic inclusions

The inclusions are small particles of insoluble substances suspended in the cytosol. A huge range of inclusions exist in different cell types, and range from crystals of calcium oxalate or silicon dioxide in plants, to granules of energy-storage materials such as starch, glycogen, or polyhydroxybutyrate. A particularly widespread example are lipid droplets, which are spherical droplets composed of lipids and proteins that are used in both prokaryotes and eukaryotes as a way of storing lipids such as fatty acids and sterols. Lipid droplets make up much of the volume of adipocytes, which are specialized lipid-storage cells, but they are also found in a range of other cell types.

Self-Quiz

1. Which one of the following eukaryotic cell structures does not contain DNA?

- a nucleus
- b mitochondrion
- c. the endoplasmic reticulum
- d. chloroplast

2. Which of the following is not an accurate description of a chromosome?

- a. It is a colored body localized in the nucleus.
- b. It is a protein and nucleic acid complex.
- c. It is the cellular structure that contains the genetic material.
- d. In eukaryotes, it is composed of many DNA molecules attached end to end.

3. A centriole is an organelle that is:

- a. present in the center of a cell's cytoplasm
- b. composed of microtubules and important for organizing the spindle fibers
- c. surrounded by a membrane
- d. part of a chromosome

4. The rough endoplasmic reticulum is:

- a. an intracellular double-membrane system to which ribosomes are attached

- b. an intracellular membrane that is studded with microtubular structures
- c. membranous structure found within mitochondria
- d. only found in prokaryotic cells

5. In the nucleus of eukaryotic cells, the genetic material is complexed with protein and organized into linear structures called:

- a. centrioles
- b. histones
- c. chromosomes
- d. plasmids

6. Which of the following statements does not apply to the nuclear envelope?

- a. It is a double membrane.
- b. It has pores through which material enters and leaves.
- c. It is continuous with the endoplasmic reticulum.
- d. It has infoldings to form cristae.

7. Some proteins are found in the plasma membrane. What part of the protein is within the membrane itself?

- a. Hydrophilic region
- b. hydroponic region
- c. hydrophobic region

- d. hydrocoel region

8. What is the simplest level of packing of the eukaryotic chromosome?
- a. the nucleolus
- b. the nucleoid
- c. the nucleosome
- d. the nucleoplasm

9. Lysosomes are formed by budding from which cellular organelle?
- a. smooth endoplasmic reticulum
- b. Golgi apparatus
- c. rough endoplasmic reticulum
- d. nucleus

10. All peroxisomes carry out this function:
- a. break down fats and amino acids into smaller molecules that can be used for energy production by mitochondria
- b. digest macromolecules using the hydrolytic enzymes they contain
- c. synthesize membrane components such as fatty acids and phospholipids
- d. control the flow of ions into and out of the cell

11. Which of the following does not apply to chloroplasts?
- a. They contain chlorophyll and the enzymes required for photosynthesis.

- b. They contain an internal membrane system consisting of thylakoids.

- c. They synthesize ATP (adenosine triphosphate) from ADP (adenosine diphosphate) and Pi (inorganic phosphate).

- d. They are bounded by two membranes, the inner of which is folded into the cristae.

Study Questions and Answers.

Study questions A

1. Name the two types of cells of living things
2. What is the major distinguishing feature of the two types of cells of living things?
3. Highlight any three (3) similarities of prokaryots and Eukaryotes
4. Explain the DNA structure of a Eukaryote and a Prokaryote
5. Why are mitochondria and chloroplast different from other organelles of the cell?

Answers to study questions A

1. *Eukaryote and a Prokaryote*
2. *The presence of a Nucleus in Eukaryote and absence of nucleus in Prokaryotes*
3.
   - vii. *They perform most of the same kinds of functions, and in the same ways.*
   - viii. *Both are enclosed by plasma membranes, filled with cytoplasm, and*
   - ix. *They cytoplasm of both cells types are loaded with small structures called ribosomes.*
   - x. *Both have DNA which carries the archived instructions for operating the cell.*
4.
   - i. *Eukaryotic DNA is linear; prokaryotic DNA is circular (it has no ends).*
   - ii. *Eukaryotic DNA is complexed with proteins called "histones," and is organized into chromosomes; prokaryotic DNA is "naked," meaning that it has no histones associated with it, and it is not formed into chromosomes. Though many are sloppy about it, the term "chromosome" does not technically apply to anything in a prokaryotic cell.*
   - iii. *A eukaryotic cell contains a number of chromosomes; a prokaryotic cell contains only one circular DNA molecule and a varied assortment of much smaller circlets of DNA called "plasmids."*

5. *Mitochondria (and chloroplasts, for that matter) have their own genetic systems. They have their own DNA, which is not duplicated in the nucleus. That DNA contains a number of the genes which are necessary to make the materials needed for aerobic cellular respiration (or photosynthesis, in the case of the chloroplast). Mitochondrial and chloroplast DNA molecules are naked and circular, like prokaryotic DNA. These*

organelles also have their own population of ribosomes, which are smaller and simpler than the ribosomes out in the general cytoplasm. Mitochondria and chloroplasts also divide on their own, in a manner similar to the binary fission of prokaryotic cells.

Study question B

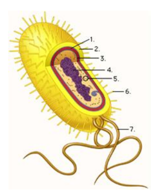
1. List the two organic compounds that form the cell membrane
2. Apart from selective permeability, cell membrane is also involved in some variety of cellular processes. List any four of these processes

Answer to study question B

1. Phospholipids and Proteins
2. i. Cell adhesion ii. Ion conductivity and signaling, serves as attachment surfaces for extracellular glycocalyx, intracellular cytoskeleton.

Study Question C

1. Identify the Features of Prokaryotic Cells
2. *Label the components of a prokaryotic cell and explain the function of each*



Study Question: D

1. With the aid of a diagram explain the structure of endoplasmic reticulum
2. List some important functions of the endoplasmic reticulum

Answer to Study Question D

1. The general structure of the endoplasmic reticulum is an extensive membrane network of cisternae (sac-like structures) held together by the cytoskeleton. The phospholipid membrane encloses a space, the cisternal space (or lumen), which is continuous with the perinuclear space but separate from the cytosol.
2. the facilitation of protein folding and the transport of synthesized proteins in sacs called cisternae.

i. Correct folding of newly-made proteins is made possible by several endoplasmic reticulum chaperone proteins

ii. Transport of proteins

iii. The endoplasmic reticulum is also part of a protein sorting pathway

iv. **Disulfide bond formation and rearrangement**: Disulfide bonds stabilize the tertiary and quaternary structure of many proteins.

v. **Drug metabolism**: The smooth ER is the site at which some drugs are modified by microsomal enzymes which include the cytochrome P450 enzymes.

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